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Tests of Reinforced Concrete Beams: Modulus of Elasticity for Various Ages & Mixtures

Civil Engineering

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TESTS OF REINFORCED CONCRETE BEAMS: MODULUS OF ELASTICITY FOR VARIOUS AGES AND MIXTURES

BY

ARTHUR LINN BEAR
SAMUEL CHARLES CAMPBELL

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

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PRESENTED, JUNE, 1908

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ARTHUR LINN BEAR

SAMUEL CHARLES CAMPBELL

ENTITLED TESTS OF REINFORCED CONCRETE BEAMS:

MODULUS OF ELASTICITY FOR VARIOUS AGES AND MIXTURES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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TESTS OF REINFORCED CONCRETE BEAMS: MODULUS OF ELASTICITY FOR VARIOUS AGES AND MIXTURES.

PART 1.

INTRODUCTION.

Reinforced concrete is now rapidly taking the place of much of the older and more expensive materials used in construction work. As reinforced concrete combines the tensile strength of steel with the compressive strength of concrete, and as the stress-deformation relation in the concrete is not constant, the action of reinforced concrete under load is more complicated than is a uniform material having a constant stress-deformation relation.

The purpose of this thesis is to investigate the stress-deformation relation, known as the modulus of elasticity, as determined from reinforced concrete beams of various ages and mixtures.

In this thesis by modulus of elasticity is meant the relation which would exist between stress and deformation if the concrete would compress uniformly at the rate it compresses for the lower stresses. This is generally called initial modulus of elasticity.

The modulus of elasticity of the concrete is an important factor in reinforced concrete design. The resisting moment in a reinforced concrete beam is taken equal to the stress

in the steel multiplied by the distance from the center of the steel to the centroid of the compressive forces in the concrete. This moment arm increases as the neutral axis rises. So, with the same stress in the steel, the resisting moment of the beam depends upon the position of the neutral axis, which in turn is determined by the modulus of elasticity of the concrete.

For several years the Engineering Experiment Station of the University of Illinois has been investigating, by means of tests, the action of reinforced concrete in various forms. Last year two of the theses prepared under its direction related to the modulus of elasticity of concrete in reinforced concrete beams. One of these theses related to the effect of ages and the other to the effect of various mixtures of reinforced concrete beams.

This thesis prepared under the direction of the Engineering Experiment Station is to investigate the effect of both age and mixture upon the modulus of elasticity. The tests were made at the Laboratory of Applied Mechanics of the University of Illinois during the winter of 1907-'08. In all, twenty-one beams, 8 in. x 11 in. x 13 ft. were tested. These ranged in ages from 4 days to 383 days. The mixtures were 1-1-2, 1-2-4, 1-4-8, and 1-5-10 by loose volume.

PART II.

THEORY AND AVAILABLE DATA.

THEORY:

Modulus of elasticity of a material is generally defined as the ratio of the unit stress to the unit deformation within the elastic limit of the material. In some materials this ratio is practically constant. In other materials, such as concrete, this ratio is not constant. As it is important in considering concrete that a definite expression should be used for this ratio, the name, "Initial Modulus of Elasticity", as used by Professor Talbot in Bulletin No. 4 of the University of Illinois Engineering Experiment Station, is adopted. This term expresses the relation which would exist between stress and deformation if the concrete compressed uniformly at the rate it compresses for the lower stresses.

For calculating the position of the neutral axis and the deformations of the top fiber and of the steel the assumption was made that a plane section before bending remains a plane section after bending. These calculations were made, partly graphically and partly algebraically, from the observed extensometer readings and the known positions of the extensometer rollers with respect to the beam. Zero deformation is considered as the deformation due to the weight of the beam and the loading apparatus. In all computations 0.002 was assumed as the ultimate unit compressive deformation for concrete. This ultimate deformation, of course, varies with the quality of the con-

crete, but as none of these beams failed by compression and as a considerable variation in this deformation affects the modulus of elasticity but little, 0.002 was chosen as the ultimate unit deformation.

The modulus of elasticity is calculated by means of a formula involving the unit compressive deformation and the position of the neutral axis. This formula, as deduced in Bulletin No. 4. of the University of Illinois Engineering Experiment Station is as follows:

$$k = \sqrt{\frac{2pn}{1-1/3g} - \frac{p^2n^2}{(1-1/3g)^2}} - \frac{pn}{1-1/3g}$$

where, k = ratio of distance between compressive face and neutral axis, to distance between compressive face and center of steel.

p = percent of reinforcement.

$n = \frac{E_s}{E_c}$ = ratio of modulus of elasticity of steel to that of concrete.

g = ratio of deformation existing in most remote fiber of the concrete to ultimate deformation in the same.

The modulus of elasticity was obtained for each beam when $g = 1/4$ and when $g = 1/2$. For $g = 1/4$ and $p = .0098$ the above equation reduces to,

$$n = \frac{k^2}{0.02138(1-k)},$$

and for $g = 1/2$ it reduces to,

$$n = \frac{k^2}{0.02352(1-k)}.$$

By means of these equations and by taking the modulus of elasticity of steel as 30,000,000 pounds per square inch the modulus of elasticity of concrete was obtained.

STRESS IN STEEL:

The stress in the steel was found both by means of the deformation of the steel and by means of the resisting moment. By the first method:

$$S = E_s e_s,$$

where,

s = Unit tensile stress in steel.

E_s = modulus of elasticity of steel.

e_s = unit deformation in steel.

By the second method:

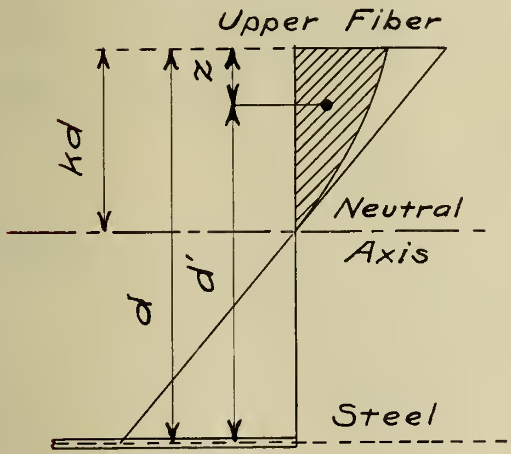


Fig. 1.

The internal resisting moment of a beam must equal the external moment. The internal bending moment equals the stress in the steel times its moment arm. This moment arm is d' of Fig. 1. From Bulletin No. 4, previously referred to, approximately this distance,

$$d' = d(1-0.35k),$$

where,

d' = moment arm of resisting couple.

d = effective depth of beam = distance from plane of upper face to plane of center of steel.

So, the internal moment,

$$M' = Sd(1-0.35k),$$

where,

M' = internal bending moment.

S = total stress in steel.

The external being moment,

$$M = 4 \times 12 \times \frac{W}{2} = 24W,$$

where,

W = applied load in pounds.

Therefore, as $M' = M$,

$$Sd(1-0.35k) = 24W,$$

or

$$S = \frac{24W}{d(1-0.35k)}.$$

STRESS IN CONCRETE:

From Bulletin No. 4 of the University of Illinois Engineering Experiment Station the compressive stress at the upper fiber,

$$c = \frac{2pf}{k} \cdot \frac{1-1/2g}{1-1/3g},$$

where,

c = stress at upper fiber.

p = percent of reinforcement.

f = stress in steel.

k = ratio of distance between compressive face and neutral axis to distance "d".

g = ratio of deformation existing in most remote fiber to ultimate deformation.

AVAILABLE DATA:

Considerable data was found relating to modulus of elasticity of concrete in beams but it is not as uniform as it probably should be. Turneaure and Maurer's "Principles of Reinforced Concrete Construction" states that 2,500,000 pounds per square inch is close enough, while Professor Talbot, in Bulletin No. 4. of the University of Illinois Engineering Experiment Station, states that a value of 2,000,000 pounds per square inch for ordinary ages and mixtures is probably about the maximum that should be used. The thesis of Messrs. Bagby and Casey as well as the thesis of Messrs. Ga lhuly, Lewis and Miller of the class of 1907 of the University of Illinois gives results more in accordance with the smaller value. The first thesis referred to gives results for various mixtures, while the other one relates to different ages.

PART III.

MATERIALS, TEST PIECES AND METHOD OF TESTING.

MATERIALS:

The materials used in making all test pieces were furnished by the Engineering Experiment Station of the University of Illinois. In return for this all the notes that were taken became the property of the Experiment Station.

In order to make the tests representative of actual conditions in practice, the materials used, excepting the steel, which was furnished by the manufacturers, was purchased in the open market.

STONE: The stone used was a good grade of limestone from Kankakee, Illinois. It was screened through a 1-inch screen. It contained about 52 per cent voids and weighed. 83 pounds per cubic foot, loose. To determine the voids a box holding one cubic foot was partly filled with water; loose stone was then slowly placed into the box until the stone filled the box and the water filled the voids between the stone.

The results of fineness tests as made by the Experiment Station are given in Table I.

SAND: The sand, which was well graded and of good quality, came from Williamsport, Indiana. It contained 41 percent voids and weighed 98.9 pounds per cubic foot, loose. The voids were determined as for the stone. Table II gives the mechanical analysis of the sand. The screening was done by hand. The samples of sand-between 1000 and 2000 grams-were taken so

as to be representative of the sand that went into the beams. Before screening the samples were thoroughly dried in an oven. The values given are averages of tests made at intervals throughout the season.

CEMENT: In all but two of the beams Chicago AA portland cement, which was purchased in the open market, was used. In the two oldest beams Universal portland cement, supplied by the manufacturers, was used. Table III gives the results of the fineness tests of both these cements.

Table IV gives the results of tests of briquettes for tensile strength. These briquettes were 7 days and 28 days old, and both of neat cement and 1-3 mixtures.

CONCRETE: The concrete was of good quality and was mixed by men experienced in that kind of work. Enough concrete was mixed at one time to make one test beam, 8 in. x 11 in. x 13 ft., 1 unreinforced beam, 6 in. x 8 in. x 3 ft. 4 in., 1 cylinder 16 in. high x 8 in. in diameter, and 3 6-in. cubes. Each of these was given the same number and was tested at approximately the same age.

Table V gives the modulus of rupture of the short beams and also the ultimate compressive strength of the cylinder and the cubes.

STEEL: The steel bars used as reinforcement in the beams were supplied by the Illinois Steel Company. They were 1/2 in. in diameter and made of mild steel.

Table VI gives the results of the tensile tests of the bars used in each beam.

TABLE No. I.

TESTS OF FINENESS OF STONE.

Mesh - Inches	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{3}$	$\frac{1}{5}$	$\frac{1}{10}$
Per Cent Passing	100.0	92.0	60.3	39.1	21.2	4.6	2.5

Results are averages of 12 separate tests.

TABLE No. II.

TESTS OF FINENESS OF SAND.

Sieve No.	Per Cent Passing
3	98.5
5	88.6
10	64.1
12	57.4
16	50.2
18	38.6
30	20.0
40	10.7
50	4.5
74	2.1
150	0.4

Results are averages of 12 separate tests.
Sieve No. is number of meshes per linear inch.

TABLE No. III.

TESTS OF FINENESS OF CEMENTS.

Sieve No.	Per Cent Passing.	
	Universal.	Chicago AA.
75	98.6	98.2
100	96.2	95.1
200	81.0	80.6

TABLE No. IV.

TENSILE TESTS OF CEMENT.

Cement	Date Tested	Ultimate Strength - Lb. Per Sq. In.			
		7 Days		28 Days	
		Neat	1-3	Neat	1-3
Universal	Average of tests made in season of 1906-1907.	506	183	646	282
Chicago AA	11-13-'07 to 12-24-'07	645	168	782	282
"	1-1-'08 to 1-21-'08	738	201	806	287
"	2-1-'08	666	182	792	284

TABLE NO. V

ULTIMATE STRENGTH OF CONCRETE, AS DETERMINED FROM AUXILIARY TEST SPECIMENS.

Concrete Same As In Beam No.	Mixture By Volume	Age Days	Modulus Of Rupture In 3 ft. Beams Lb. Per Sq. In.	Ultimate Compressive Strength	
				8-In x 16-In Cylinder Lb. Per Sq. In.	6-In Cubes. Lb. Per Sq. In.
341.2	1-1-2	14	304	1730	2517
342.1	1-1-2	62	517	4120	
331.3	1-2-4	11	140		407
331.1	1-2-4	6	29	445	836
332.1	1-2-4	11	213	880	1517
333.2	1-2-4	14	235	785	1243
333.1	1-2-4	17	157		668
334.3	1-2-4	34	345	1818	2230
334.2	1-2-4	29	345		2260
334.1	1-2-4	33	292		
331.2	1-2-4	58	242	1010	1500
335.1	1-2-4	63	330		2640
335.2	1-2-4	64	372	955	2385
322.5	1-2-4	385	349	3110	
322.6	1-2-4	369	186	3530	4237
351.2	1-4-8	14	97	379	
352.1	1-4-8	62	224	1195	1573
352.2	1-4-8	63		712	1008
362.2	1-5-10	69	88	368	815
361.1	1-5-10	58	173	660	1025
362.1	1-5-10	60		381	870

TABLE No. VI.

TENSILE TESTS OF

$\frac{1}{2}$-IN. ROUND STEEL REINFORCING BARS

Bars Used In Beam No.	Elongation Per Cent	Load- Lb. Per Sq. In.	
		Elastic Limit.	Ultimate Strength
341.2	26	40500	62400
342.1	28	41500	62600
331.3	29	40800	60700
331.1	27	39600	60900
332.1	26	40500	60400
333.2	27	41600	62300
333.1	28	39600	60900
334.3	27	41300	62400
334.2	28	39700	61300
334.1	28	39500	59400
331.2	26	41700	62300
335.1	29	40900	62500
335.2	29	39700	60800
322.5	30	37200	52700
322.6			
351.2	28	40000	61000
352.1	28	42000	62200
352.2	28	41000	61300
362.2	28	40400	61200
361.1	28	39900	61000
362.1	28	40200	61000

TEST PIECES:

The beams used in making the tests were of standard size, being 8 in. x 11 in. x 13 ft. The distance between supports in the tests was 12 feet. The depth from the compressive face to the plane of the reinforcement, which consisted of 4 1/2-inch plain, round, mild steel rods, 12 feet 6 in. long, was 10 in. The rods were placed in a horizontal plane 2 inches between centers. The effective cross-section of thebeam was 80 sq. in. and that of the steel 0.785 sq. in., thus, making the reinforcement 0.98 percent of the concrete. Each beam weighed about 1200 pounds making the weight of the concrete about 150 pounds per cu. foot.

Table VII gives the brand of cement, the age, and the mixture, both by volume and weight, of each beam.

MAKING OF BEAMS: The beams were made on the floor of the concrete laboratory, a strip of building paper being placed beneath the forms. The forms, made of 2 in. pine, were of the ordinary knock-down, reversible type. Braces were placed every 3 feet along the forms to prevent bulging of the sides. The details of the forms are shown in Figure 2. The proportions of the concrete were made by loose volume and checked by weight. ~~The proportions of the concrete were made by loose volume and checked by weight~~. The mixing was done by hand with shovels on a large steel plate. The dry sand and cement were first mixed together, then the stone, having been previously dampened, was added, after which enough water was put in to make a rather wet mixture, and then the whole was turned until it was of uniform

consistency.

A 1-in. layer of concrete was first placed in the bottom of the forms. On this was laid the 4 1/2-in. bars, 2 in. center to center. No tamping was done in the plane of the steel. The rest of the concrete was placed in the forms in 3 in. layers, each layer being well tamped. After tamping, a spade was forced between the concrete and the side of the form so as to make a smooth surface. The beams were sprinkled twice a day. The forms were removed 4 days after the beams were made. The temperature of the laboratory was between 55 and 65 degrees Fahrenheit. Table VIII gives the weights of the materials and the percent of water in each beam.

TABLE No. VII.

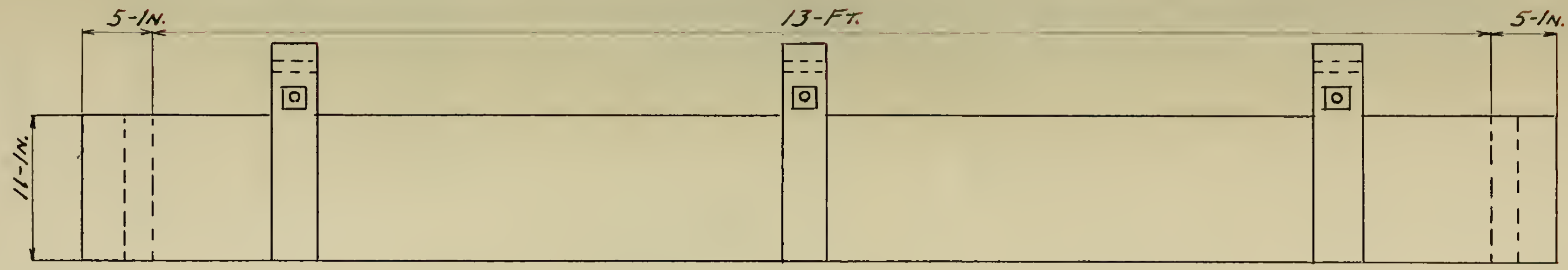
DATA ON BEAMS.

Beam No.	Age Days	Mixture By Volume	Mixture By Weight	Portland Cement Used
341.2	14	1-1-2	1- 1.2 - 2.2	Chicago AA
342.1	59	1-1-2	1- 1.3 - 2.1	"
331.3	4	1-2-4	1- 2.5 - 4.2	"
331.1	7	1-2-4	1- 2.3 - 4.0	"
332.1	7	1-2-4	1- 2.4 - 4.1	"
333.2	15	1-2-4	1- 2.6 - 4.1	"
333.1	17	1-2-4	1- 2.6 - 4.3	"
334.3	28	1-2-4	1- 2.5 - 4.2	"
334.2	30	1-2-4	1- 2.6 - 4.3	"
334.1	33	1-2-4	1- 2.7 - 4.2	"
331.2	58	1-2-4	1- 2.4 - 4.0	"
335.1	62	1-2-4	1- 2.6 - 4.1	"
335.2	69	1-2-4	1- 2.4 - 4.2	"
322.5	383	1-2-4	1- 2.4 - 3.9	Universal
322.6	383	1-2-4	1- 2.2 - 3.9	"
351.2	14	1-4-8	1- 5.2 - 8.6	Chicago AA
352.1	62	1-4-8	1- 5.1 - 8.2	"
352.2	65	1-4-8	1- 5.1 - 8.2	"
362.2	63	1-5-10	1- 6.3 - 10.1	"
361.1	66	1-5-10	1- 5.5 - 9.2	"
362.1	67	1-5-10	1- 6.0 - 10.0	"

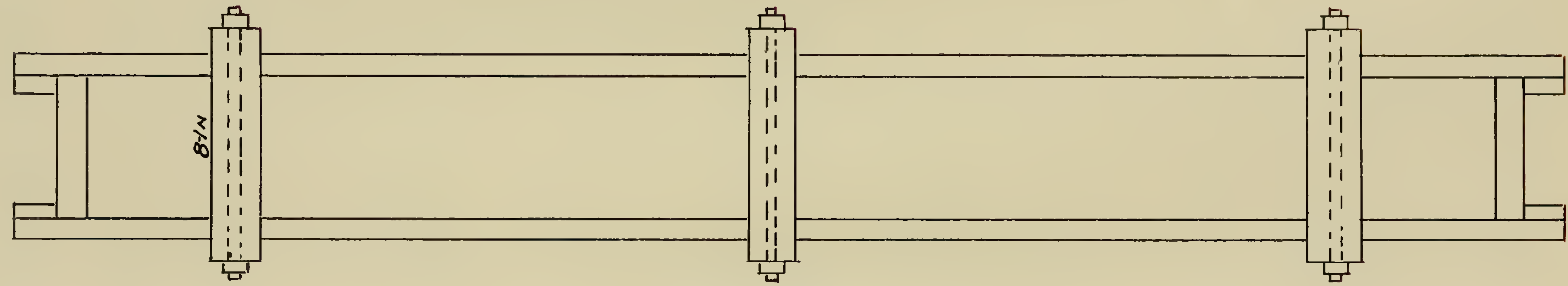
TABLE No. VIII

WEIGHT OF MATERIALS AND WATER USED.

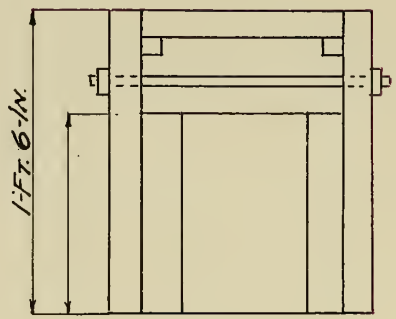
Beam No.	Mixture By Volume	Materials - Lb. Cement	Sand	Stone	Total	Water	Water Per Cent Of Total
341.2	1-1-2	317	390	685	1392	140	10.1
342.1	1-1-2	239	389	448	1076	125	11.6
331.3	1-2-4	186	460	782	1368	130	9.5
331.1	1-2-4	175	409	706	1290	102	7.9
332.1	1-2-4	227	546	939	1712	140	8.2
333.2	1-2-4	177	456	734	1367	120	8.8
333.1	1-2-4	188	490	809	1487	120	8.1
334.3	1-2-4	222	552	928	1702	150	8.8
334.2	1-2-4	172	448	737	1357	100	7.4
334.1	1-2-4	193	508	821	1522	125	8.2
331.2	1-2-4	193	473	781	1357	140	10.3
335.1	1-2-4	174	446	716	1236	113	9.1
335.2	1-2-4	196	477	816	1489	140	9.3
322.5	1-2-4	208	490	816	1514	137	9.1
322.6	1-2-4	196	436	768	1400	120	8.6
351.2	1-4-8	93	480	799	1372	105	7.7
352.1	1-4-8	96	496	809	1401	100	7.1
352.2	1-4-8	95	487	779	1361	100	7.4
362.2	1-5-10	88	534	876	1498	107	7.1
361.1	1-5-10	94	513	860	1467	115	7.8
362.1	1-5-10	87	544	881	1512	100	6.6



SIDE VIEW



TOP VIEW



END VIEW

SKETCH
OF
BEAM FORM

FIGURE 2

METHOD OF TESTING:

The beams were tested in the 200,000 lb. Olsen testing machine. They were handled in the testing laboratory by means of two trolleys and tackles running on an over-head track. When in the machine ready for testing, the beams were supported on the table of the machine by rocking supports 12 feet apart. The tops of these supports were curves of 2 in. radius and the bases were of 12 in. radius, thus, allowing a rocking action as the beam deflected. Bearing plates 4 in. x 1 in. x 10 in. were placed between the rocker and the beam, with a thin sheet of rubber gasket between the plates and the beam to secure an even bearing. Similar bearing plates, with rubber gasket beneath them, were placed on top of the beam at the 1/3 points. On each of these latter plates a 2 in. turned steel roller was placed at right angles to the axis of the beam. On these rollers rested a 7 in. I-beam at the center of the span of which the load was applied by the head of the machine to a spherical surface attached to the I-beam.

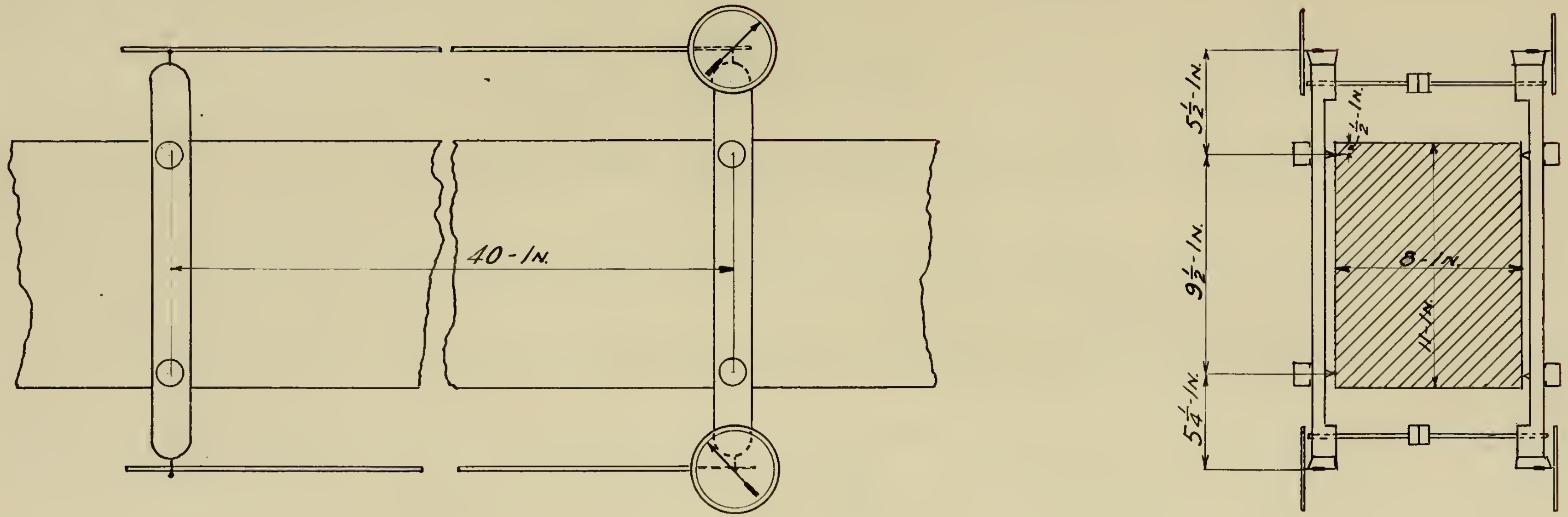
The load was usually applied in 1000-lb. increments. Readings were taken of the deflection of the center of the beam and also of the longitudinal elongation and shortening of the steel and of the upper fibers respectively. For some of the leaner mixtures the load-increment was 500 lbs. The loads were applied slowly, the increase of deflection averaging about 0.03 in. per minute.

The deflection at the center of the beam was obtained by means of a fine silk thread stretched at a constant tension

between points over the supports and at the middle of the depth of the beam. This thread passed in front of a scale attached at the center of the span and readings were obtained by lining up the thread and its reflection in a mirror to which the scale was attached. These readings were accurate to 0.01 in.

The longitudinal elongation and shortening was obtained by means of the extensometers shown in Figure 3. The two yokes were placed symmetrically with respect to the center of the span and 40 in. apart. The upper pairs of contact points were placed 1/2 in. below the top of the beam and the lower pairs 10 in. below the top, at the plane of the reinforcement. On the one yoke the center of the upper roller and dial was placed 5 1/2 in. above the upper contact point and the lower ones 5 1/4 in. below the lower contact point, thus, making the distance, center to center of dials, 20 1/4 in. The rollers were 0.5 in. in circumference and the dials were so graduated that readings were obtained to 0.0001 in. The other yoke had a fixed pin in the place of the roller and dial. On this pin rested a notched end of a 1/4-in. round, hollow, brass rod. The other end of the rod, which was a flat piece of steel about 1/2 in. wide, rested upon the roller. The rods, remaining a constant length during the test, recorded by means of the movement of the roller and pointer any change of the length between the yokes.

The arrangement of the beam and apparatus is shown in Figure 4.

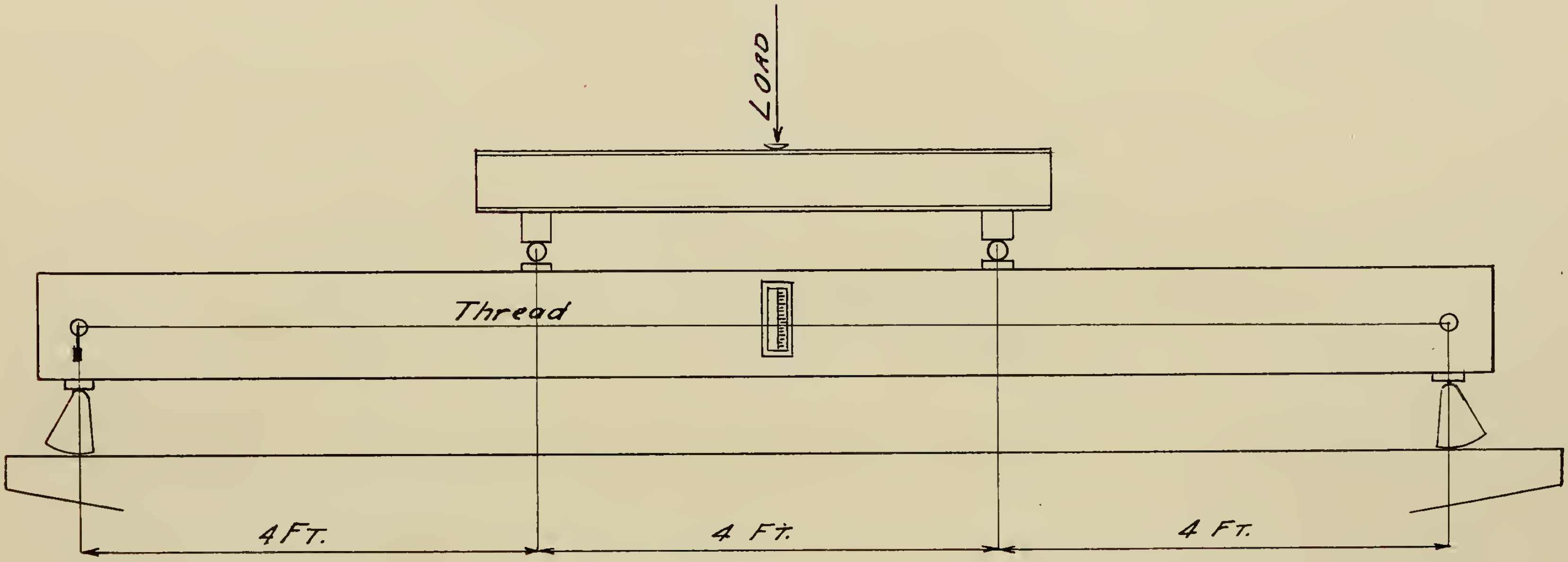


SIDE VIEW

END VIEW

EXTENSOMETERS ON BEAM

FIGURE 3



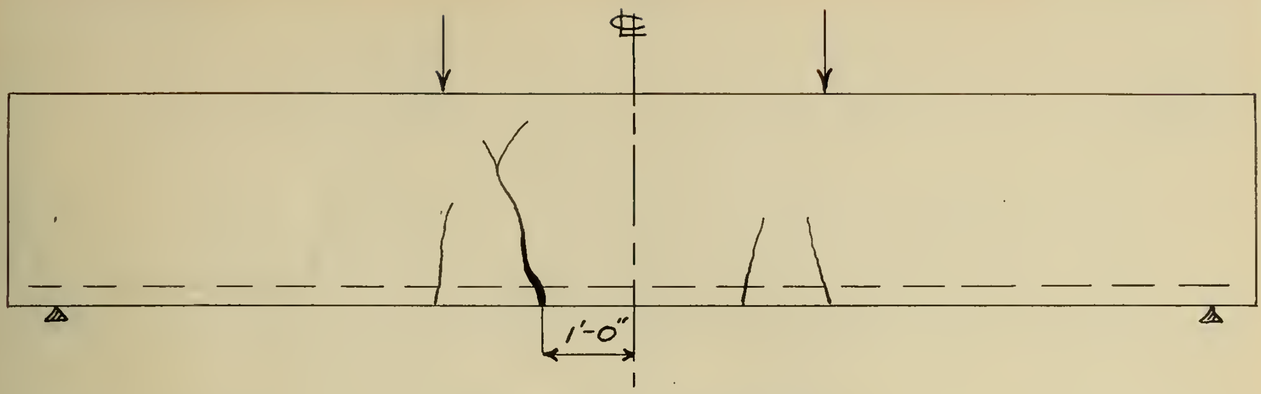
POSITION OF BEAM IN THE MACHINE

FIGURE 4

EXPERIMENTAL DATA.

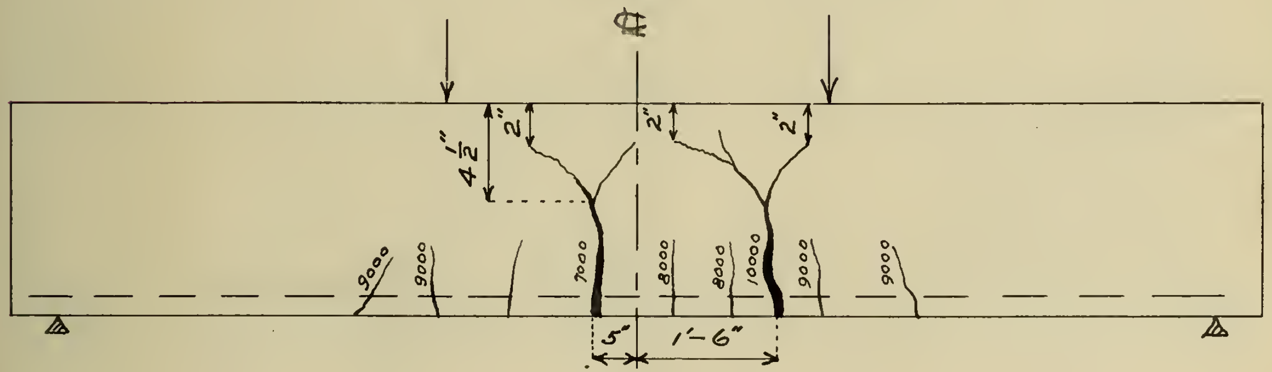
OBSERVED DATA.

In this part a short description of each beam and its action during the test is given. A sketch of each beam shows where and at what load each crack appears and also the manner of failure. Unless otherwise noted all cracks shown are those thatappeared upon one side of the beam.



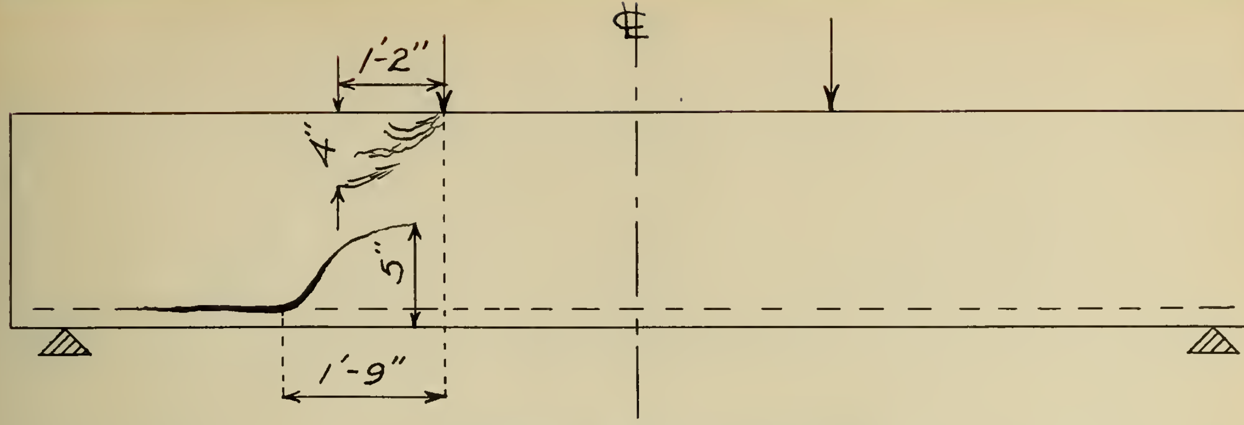
Beam No. 341.2

Mixture ..... By volume ..... 1 - 1 - 2.
By weight ..... 1 - 1.23 - 2.16.
Age .... 14 days
Maximum load .... 11320 pounds.
Method of failure .... Tension.



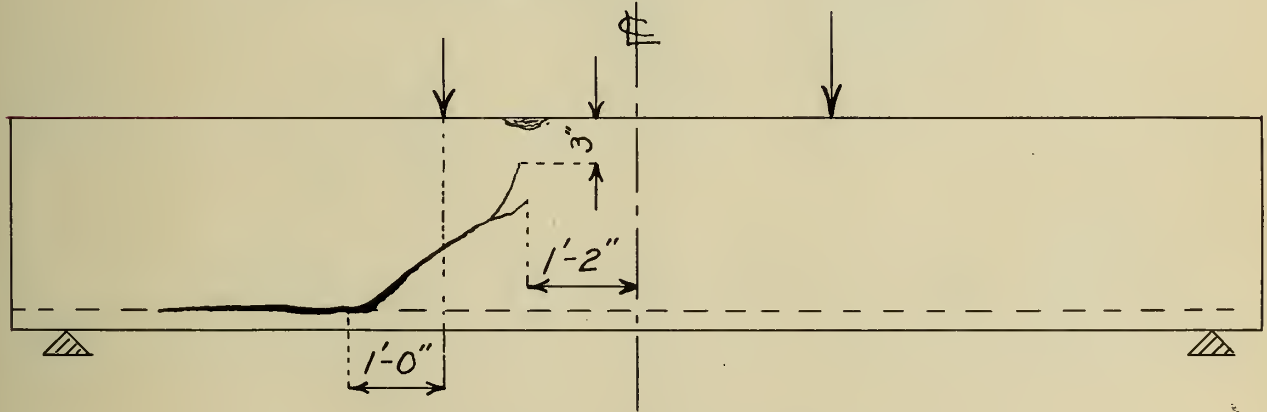
Beam No. 342.1

Mixture ..... By volume ..... 1 - 1 - 2
By weight ..... 1 - 1.26 - 2.18
Age ..... 59 days.
Maximum load ..... 12200 pounds.
Method of failure ..... Tension.



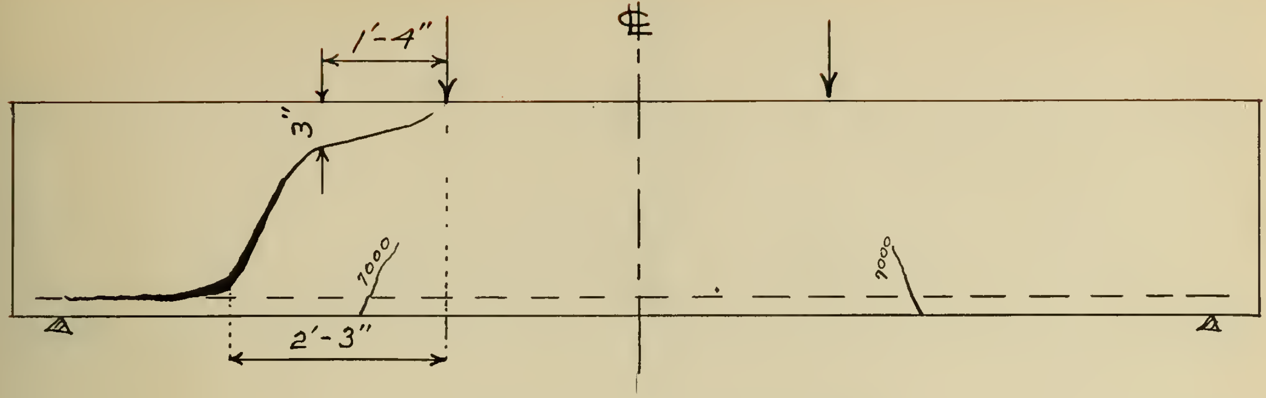
Beam No. 331.3

Mixture..... By volume..... 1 - 2 - 4
By weight.... 1 - 2.47 - 4.21
Age..... 4 days
Maximum load..... 2900 pounds.
Method of failure.... Slowly diagonal tension, then crushing on top.
Failure crack first appeared at load of 2800 pounds.



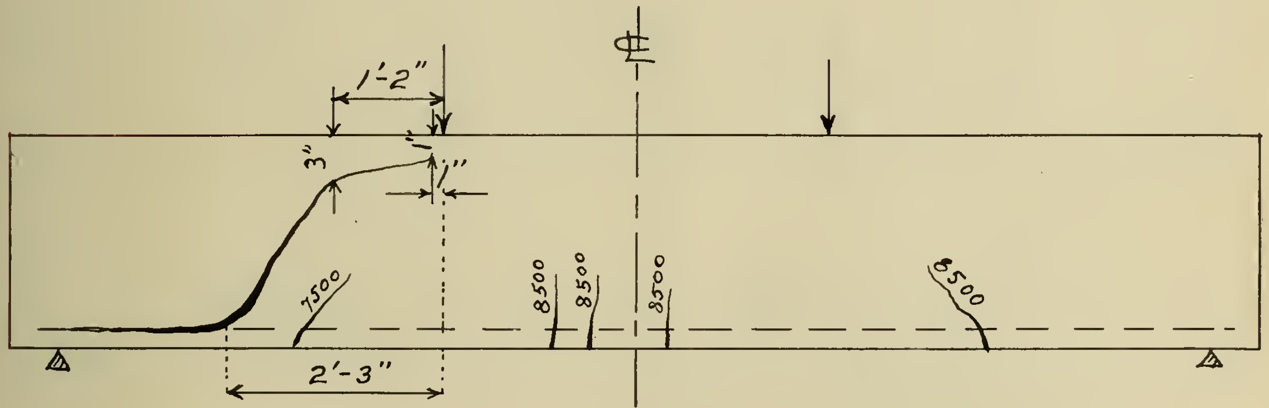
Beam No. 333.1

Mixture........By volume 1' - 2 - 4
By weight 1 - 2.60 - 4.30
Age...... 17 days.
Maximum load...... 7500 pounds.
Method of failure..... Diagonal tension.
Failure crack first appeared at load of 7000 pounds.



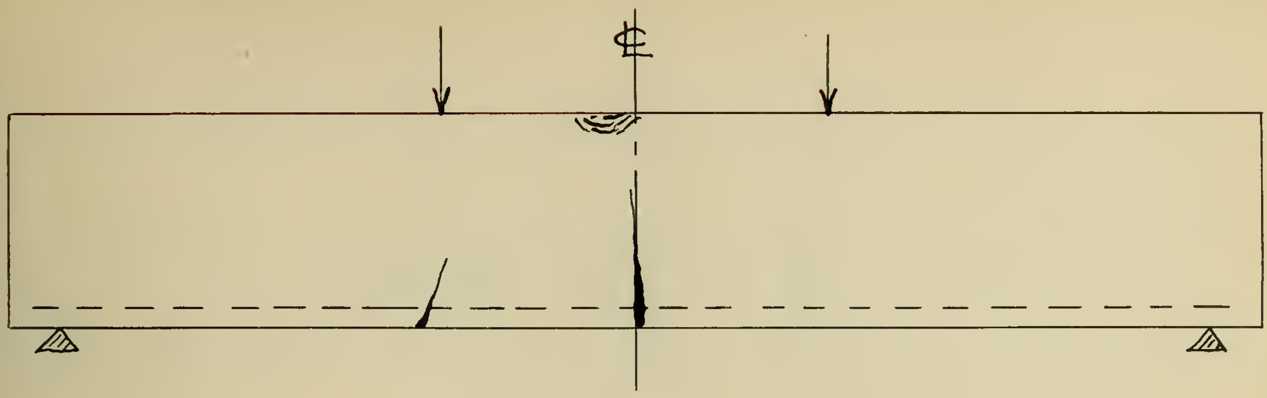
Beam No. 331.1

Mixture ..... By volume 1-2-4
By weight 1-2.34-4.04
Age ..... 7 days.
Maximum load ..... 7750 pounds.
Method of failure ..... Diagonal tension.
No hair crack was noticed where failure occurred



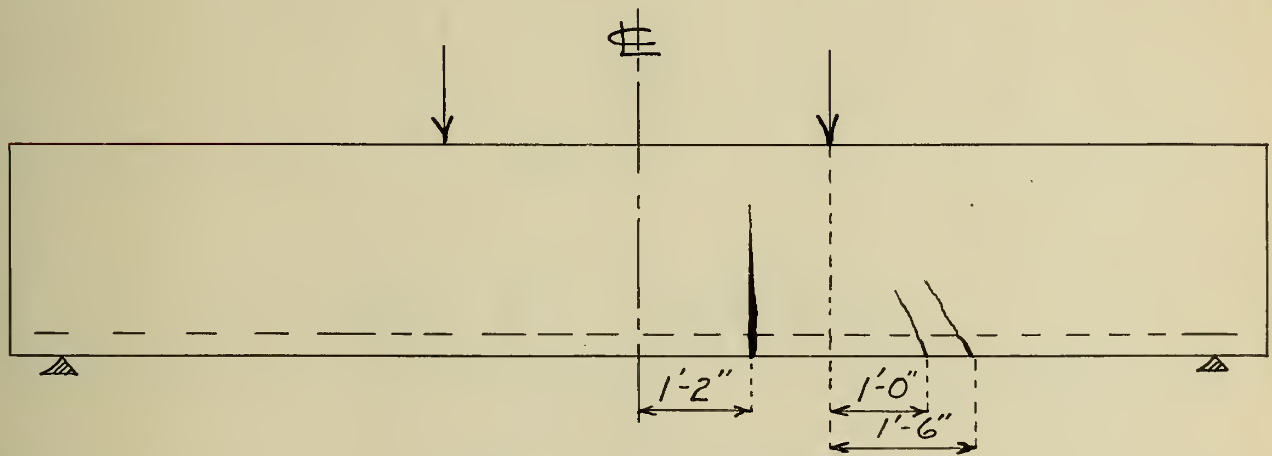
Beam No. 332.1

Mixture ..... By volume 1-2-4
By weight 1-2.41-4.14
Age ..... 7 days
Maximum load ..... 8600 pounds.
Method of failure ..... Diagonal tension.
Failure crack first appeared at load of 8000 pounds.



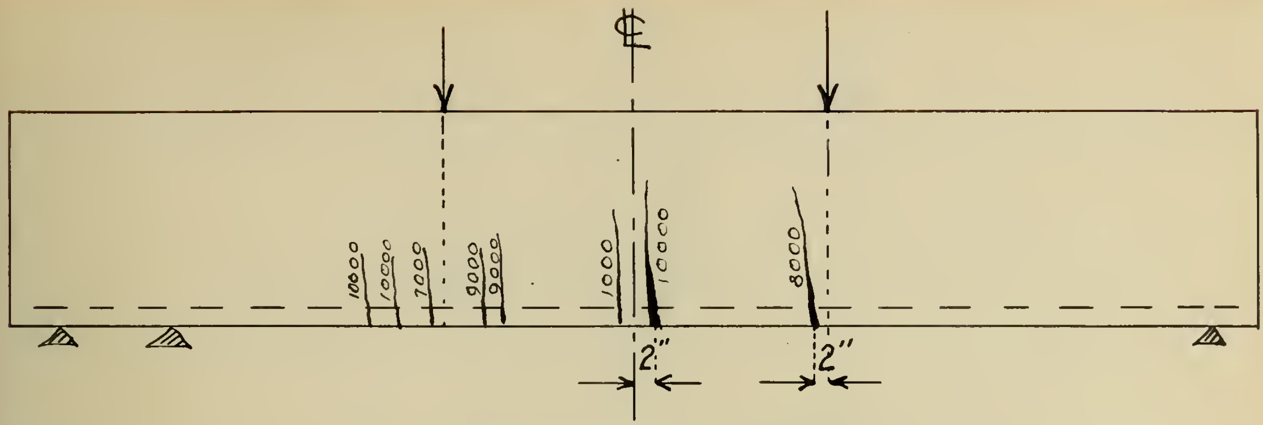
Beam No. 333.2

Mixture ..... By volume 1-2-4
By weight 1-2.58-4.14
Age ..... 15 days.
Maximum load ..... 9040 pounds.
Method of failure ..... Tension and compression almost at same time.



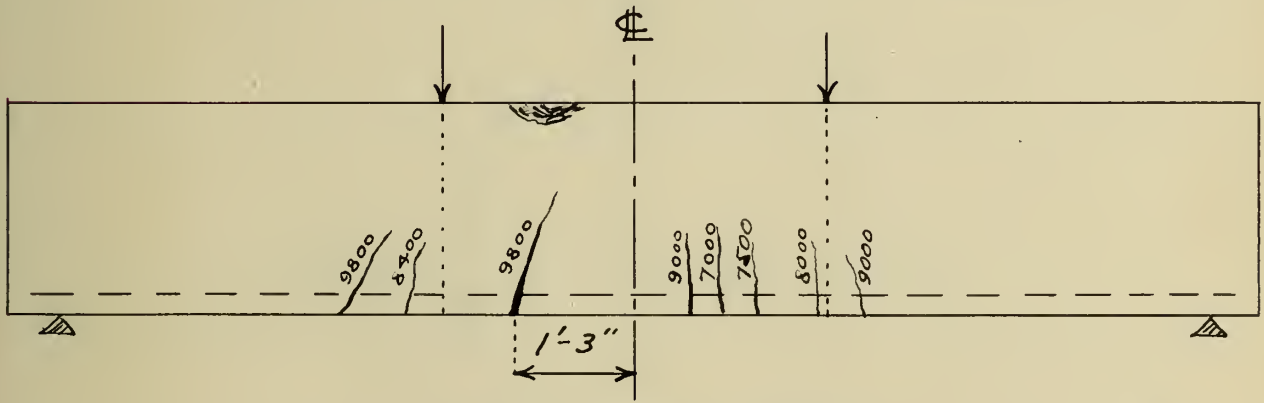
Beam No. 334.1

Mixture ..... By volume 1-2-4
By weight 1-2.68-4.25
Age ..... 33 days
Maximum load ..... 11800 pounds.
Method of failure ..... Tension.



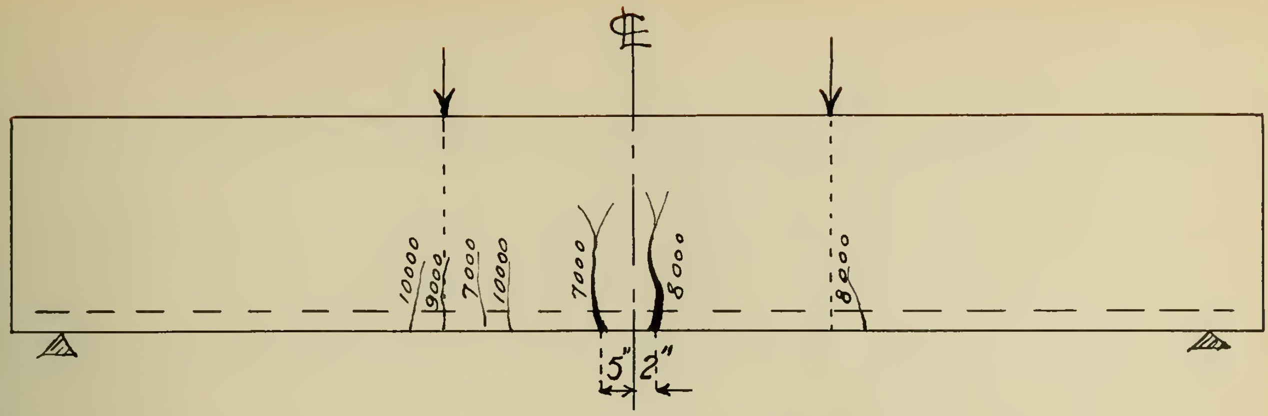
Beam No. 334.2

Mixture ..... By volume ..... 1 - 2 - 4
By weight ..... 1 - 2.60 - 4.28
Age ..... 30 days
Maximum load ..... 11 300 pounds.
Method of failure ..... Tension.
After maximum was passed the fast speed was turned on until compression began on top.



Beam No. 334.3

Mixture ..... By volume ..... 1 - 2 - 4
By weight ..... 1 - 2.48 - 4.18
Age .. 28 days.
Maximum load ..... 9800 pounds.
Method of failure ..... Tension.



Beam No. 335.1

Mixture ..... By volume 1-2-4

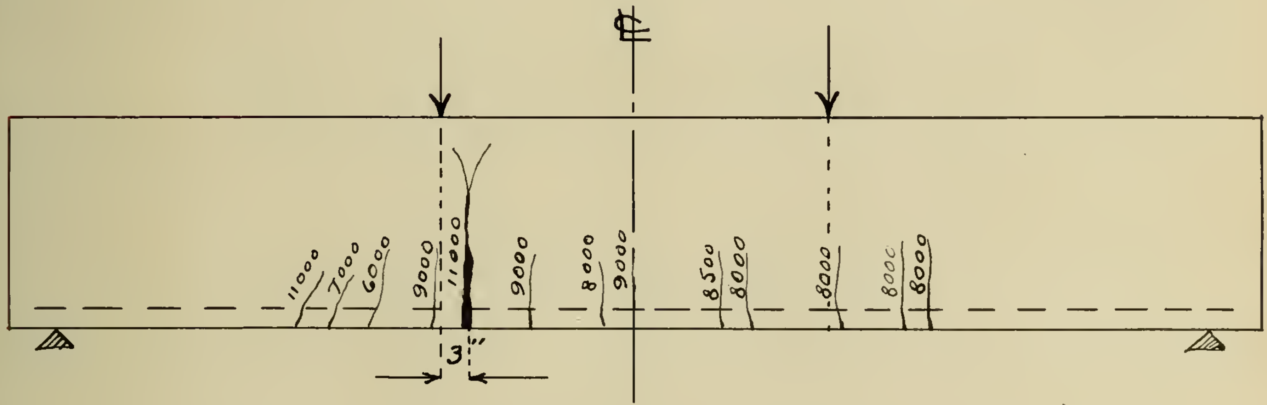
By weight 1-2.56-4.11

Age ..... 62 days

Maximum load ..... 11800 pounds.

Method of failure ..... Tension.

Fast speed used after maximum was passed.



Beam No. 335.2

Mixture ..... By volume 1-2-4

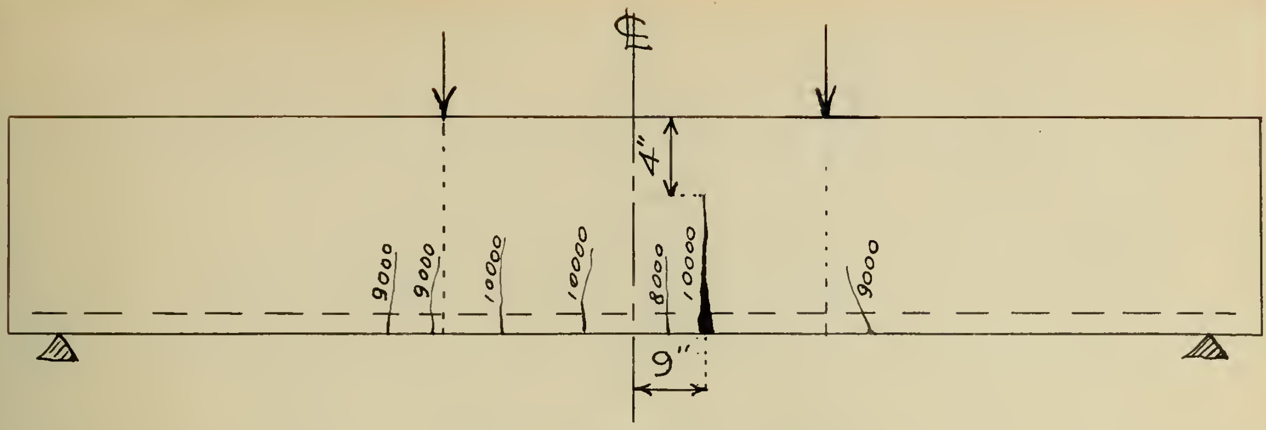
By weight 1-2.43-4.16

Age ..... 69 days.

Maximum load ..... 11200 pounds.

Method of failure ..... Tension.

Fast speed used after maximum was passed.



Beam No. 331.2

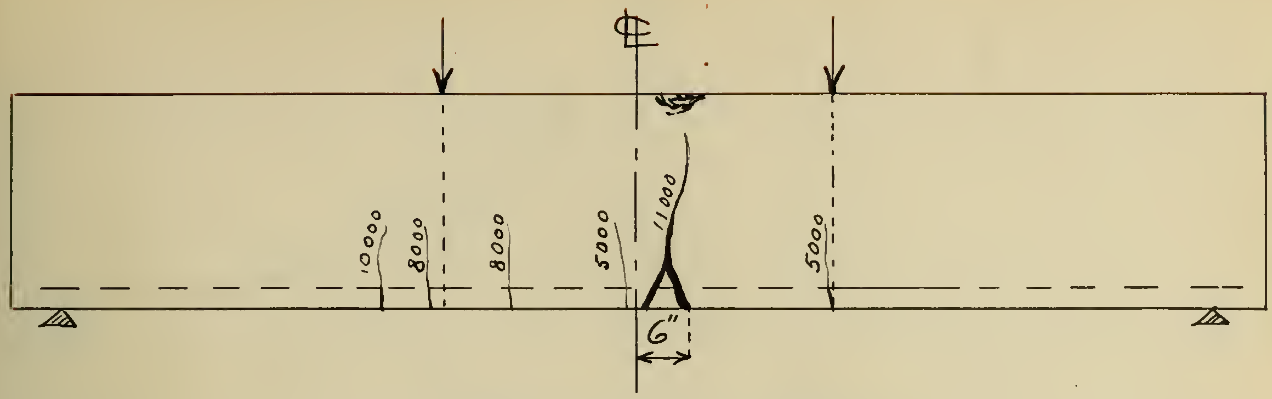
Mixture..... By volume..... 1-2-4

By weight..... 1-2.60-4.28

Age..... 58 days.

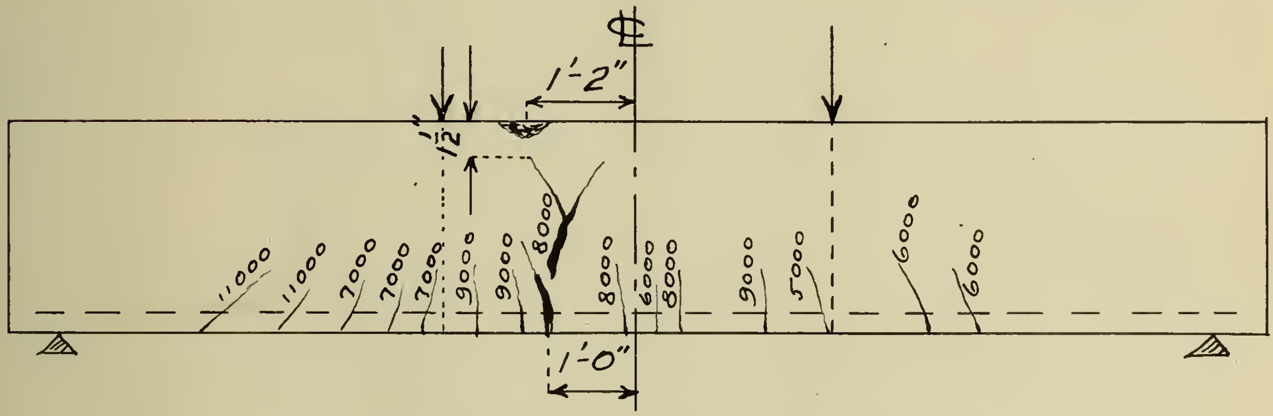
Maximum load..... 12000 pounds.

Method of failure..... Tension.



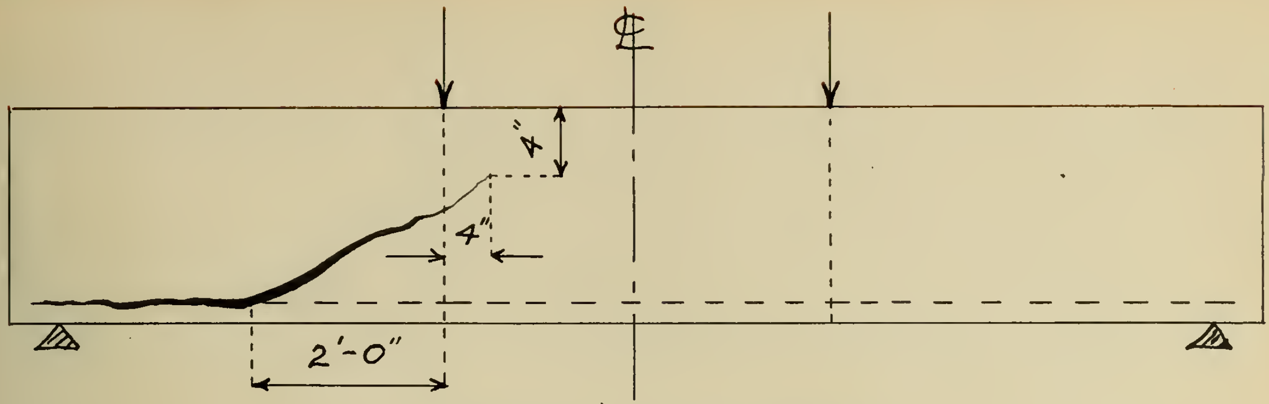
Beam No. 322.5

Mixture ..... By volume 1-2-4
By weight 1-2.36-3.93
Age ..... 383 days.
Maximum load ..... 12300 pounds.
Method of failure ..... Tension.
After maximum was passed, fast speed was used until compression began on top.



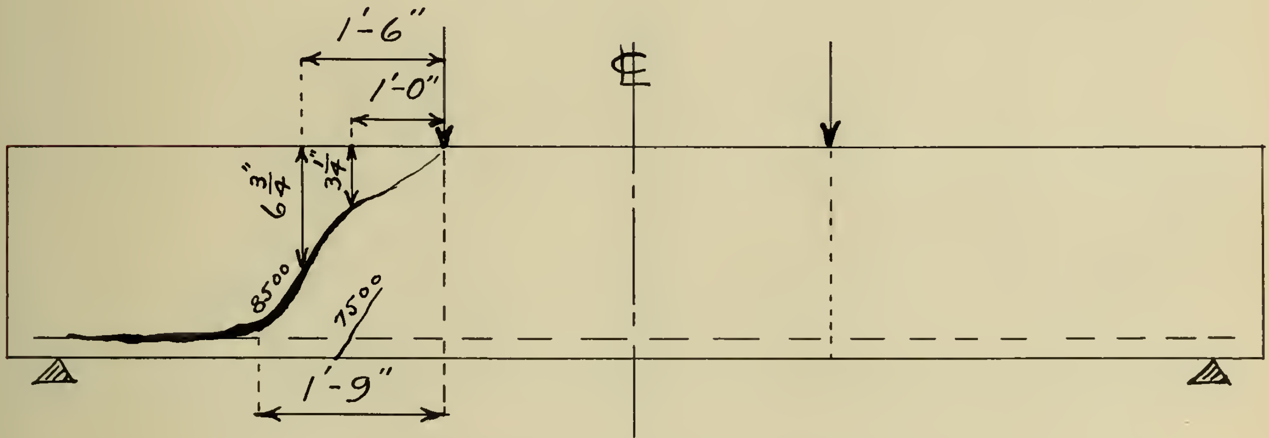
Beam No. 322.6

Mixture ..... By volume 1-2-4
By weight 1-2.22-3.92
Age 383 days.
Maximum load ..... 11300 pounds.
Method of failure ..... Tension.



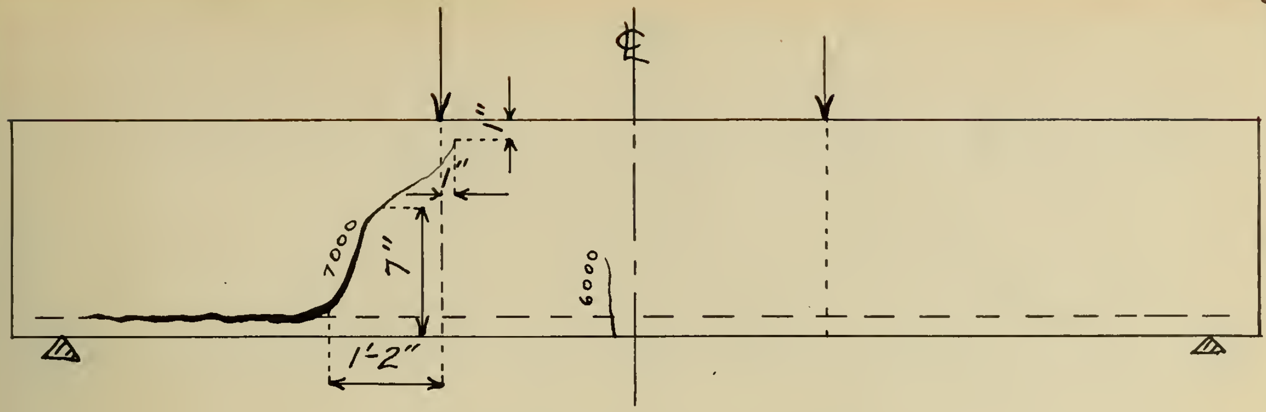
Beam No. 351.2

Mixture ..... By volume 1-4-8
By weight 1-5.16-8.59
Age ..... 14 days.
Maximum load..... 3340 pounds.
Method of failure..... Diagonal tension.



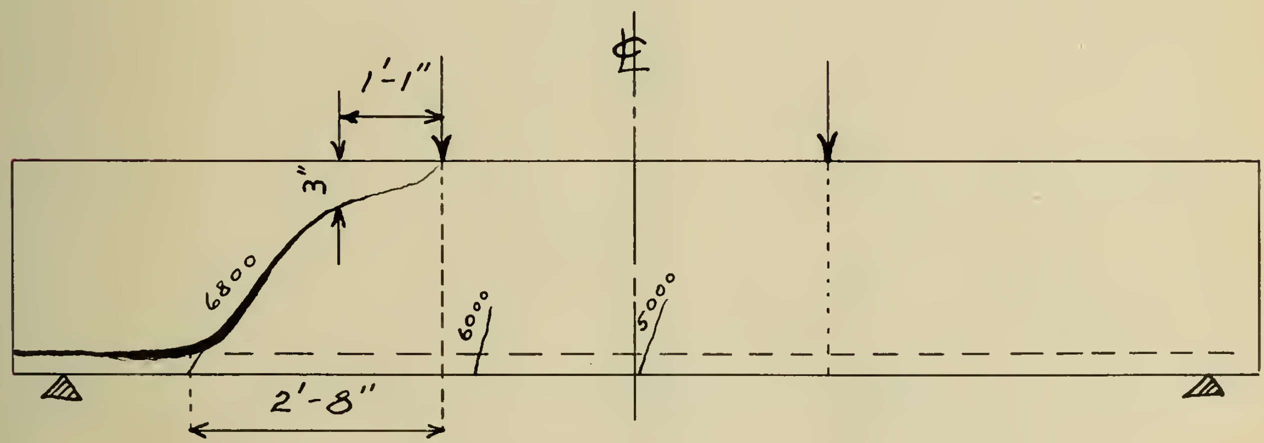
Beam No. 352.1

Mixture ..... By volume..... 1-4-8
By weight..... 1-5.08-8.20
Age ..... 62 days.
Maximum load ..... 9100 pounds.
Method of failure .....Diagonal tension, sudden break.



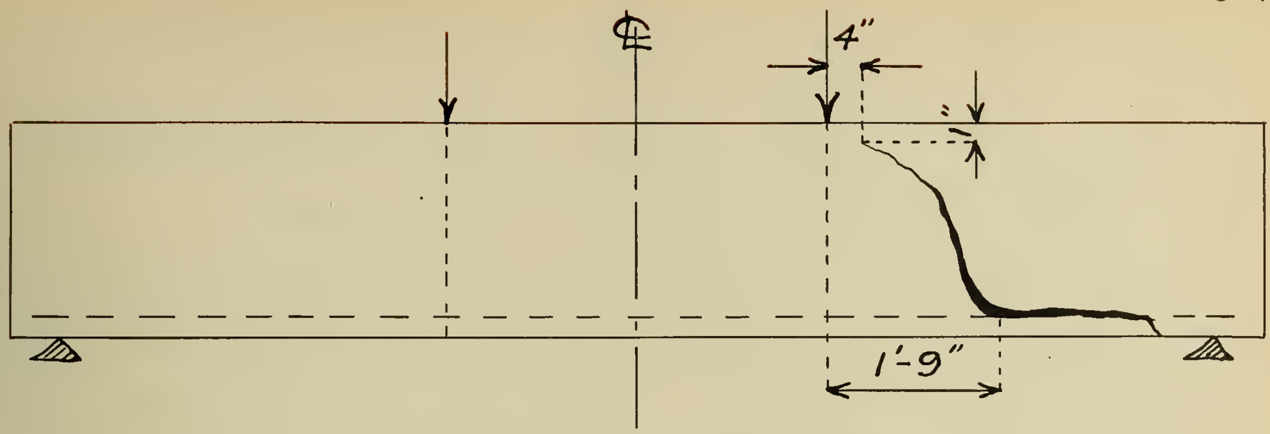
Beam No. 352.2

Mixture ..... By volume 1-4-8
By weight 1-5.13-8.20
Age ..... 65 days.
Maximum load ..... 7400 pounds.
Method of failure ..... Diagonal tension.



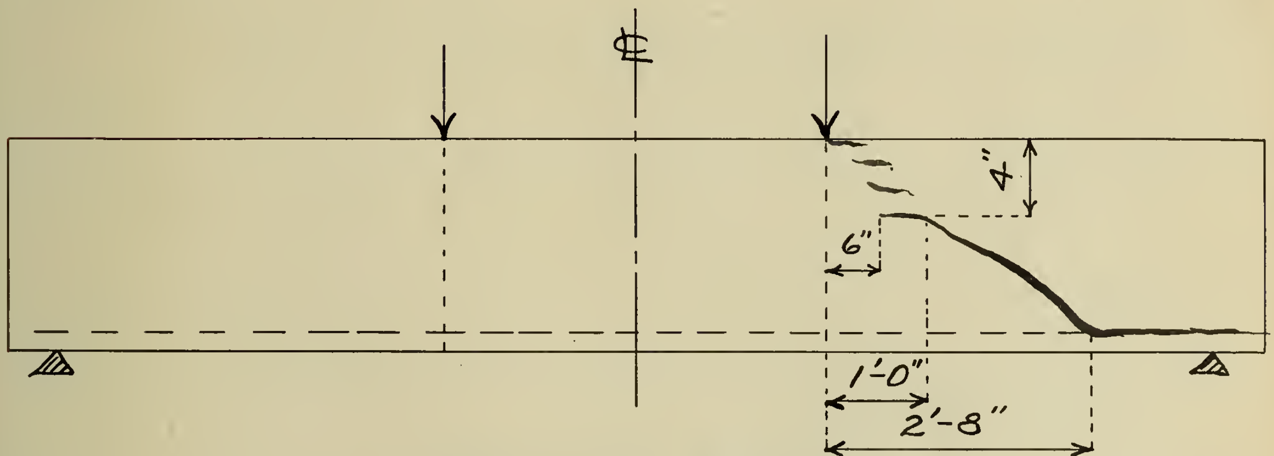
Beam No. 361.1

Mixture ..... By volume 1-5-10
By weight 1-5.46-9.16
Age ..... 66 days
Maximum load ..... 6800 pounds
Method of failure ..... Diagonal tension, sudden break.



Beam No. 362.1

Mixture ..... By volume 1-5-10
By weight 1-6.05-9.96
Age ..... 67 days.
Maximum load ..... 6700 pounds.
Method of failure ..... Diagonal tension.



Beam No. 362.2

Mixture ..... By volume 1-5-10
By weight 1-6.25-10.11
Age ..... 68 days.
Maximum load ..... 4300 pounds.
Method of failure ..... Diagonal tension.
Beam was very crumbly.

EXPERIMENTAL DATA:

ORIGINAL READINGS AND CURVES: This part contains the original readings together with the results of calculations for unit deformation in the upper fiber and the steel, and also the position of the neutral axis. The applied load is the total load on the beam exclusive of the weight of the beam and the loading and measuring apparatus. The deflection is the deflection in inches of the center of the beam. The extensometer readings are the original readings in inches. Numbers 1 and 3 are at the top and numbers 2 and 4 are at the bottom. The unit-deformation and the position of the neutral axis are computed as explained in Part III.

The curves drawn for each beam explain themselves.

BEAM No. 341.2 MIXTURE...1-1-2 AGE...14 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.01	.0022	.0026	.0027	.0028	.000028	.000034	.454
2000	0.02	.0059	.0061	.0064	.0066	.000073	.000082	.472
3000	0.04	.0099	.0105	.0107	.0112	.000125	.000135	.480
4000	0.07	.0163	.0164	.0173	.0183	.000199	.000224	.471
5000	0.14	.0259	.0267	.0307	.0314	.000304	.000402	.430
6000	0.16	.0350	.0364	.0435	.0438	.000408	.000572	.412
7000	0.25	.0423	.0444	.0537	.0542	.000498	.000707	.404
8000	0.26	.0509	.0534	.0645	.0652	.000593	.000860	.404
9000	0.36	.0592	.0623	.0753	.0761	.000700	.000995	.408
10000	0.39	.0682	.0717	.0858	.0871	.000793	.001140	.407
11000	0.45	.0783	.0812	.0969	.0989	.000900	.001290	.409
11320	0.48	MAXIMUM.		FAILURE		....TENSION.		

BEAM No. 342.1 MIXTURE...1-1-2 AGE...59 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0024	.0031	.0017	.0015	.000041	.000012	.772
2000	0.03	.0051	.0047	.0038	.0040	.000063	.000037	.628
3500	0.05	.0094	.0089	.0073	.0079	.000124	.000082	.602
4000	0.07	.0115	.0109	.0092	.0100	.000151	.000105	.590
5000	0.08	.0146	.0139	.0123	.0131	.000189	.000143	.570
6000	0.10	.0184	.0177	.0164	.0169	.000237	.000191	.554
7000	0.14	.0247	.0242	.0249	.0254	.000350	.000352	.498
8000	0.21	.0359	.0364	.0432	.0434	.000420	.000558	.420
9000	0.26	.0429	.0446	.0550	.0556	.000495	.000732	.398
10000	0.31	.0503	.0513	.0642	.0655	.000560	.000865	.390
11000	0.31	.0577	.0649	.0745	.0763	.000621	.001022	.378
12000	0.41	.0641	.0657	.0839	.0861	.000700	.001150	.378
12200	0.49	MAXIMUM.		FAILURE....		TENSION.		
11600	0.56	.0927	.0959	.1509	.1538	.000845	.002200	.280

BEAM No. 331.3 MIXTURE.....1-2-4 AGE.....4 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
500	0.02	~~.0052~~	.0036	.0020	~~.0015~~	.000055	.000014	.803
1000	0.05	~~.0140~~	.0117	.0067	~~.0069~~	.000149	.000041	.788
1500	0.10	~~.0271~~	.0238	.0150	~~.0145~~	.000302	.000105	.742
2000	0.16	~~.0446~~	.0412	.0249	~~.0241~~	.000621	.000195	.761
2500	0.18	~~.0754~~	.0716	.0406	~~.0400~~	.001098	.000288	.792
2800	0.44	~~.1213~~	.1174	.0612	~~.0613~~	.001832	.000375	.830
2900	MAXIMUM			FAILURE..... DIAGONAL TENSION.				

BEAM No. 331.1 MIXTURE....1-2-4 AGE....7 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0044	.0046	.0047	.0047	.000027	.000031	.490
2000	0.07	.0122	.0137	.0122	.0128	.000166	.000149	.528
3000	0.12	.0231	.0241	.0238	.0245	.000307	.000284	.520
4000	0.19	.0351	.0421	.0339	.0371	.000507	.000406	.555
5000	0.27	.0509	.0541	.0470	.0520	.000680	.000578	.541
6000	0.38	.0730	.0774	.0623	.0701	.001002	.000798	.561
7000	0.53	.1074	.1122	.0835	.0939	.001502	.000950	.620
7700	0.73	.1567	.1637	.1073	.1237	.002300	.001108	.675
7750	MAXIMUM.			FAILURE.....DIAGONAL TENSION.				

BEAM No. 332.1 MIXTURE 1-2-4 AGE 7 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.03	.0051	.0053	.0047	.0045	.000065	.000048	.574
1500	0.04	.0073	.0079	.0065	.0068	.000102	.00073	.582
2000	0.06	.0108	.0116	.0097	.0106	.000148	.000114	.565
2500	0.09	.0156	.0168	.0152	.0168	.000209	.000184	.532
3000	0.11	.0208	.0223	.0209	.0219	.000273	.000258	.514
3500	0.14	.0259	.0278	.0262	.0275	.000345	.000325	.513
4000	0.17	.0317	.0344	.0322	.0340	.000422	.000385	.512
4500	0.20	.0379	.0411	.0386	.0407	.000505	.000470	.512
5000	0.24	.0438	.0480	.0443	.0458	.000588	.000532	.520
5500	0.28	.0508	.0559	.0509	.0536	.000680	.000620	.519
6000	0.31	.0582	.0649	.0571	.0607	.000820	.000642	.550
6100	0.33	.0605	.0683	.0590	.0605	.000850	.000660	.550
6500	0.36	.0663	.0748	.0630	.0659	.000930	.000732	.556
7000	0.40	.0751	.0842	.0700	.0732	.001065	.000800	.567
7500	0.45	.0862	.0963	.0777	.0821	.001212	.000888	.579
8000	0.51	.0997	.1109	.0881	.0921	.001432	.000978	.593
8500	0.59	.1177	.1298	.0990	.1049	.001800	.001040	.634
8600	MAXIMUM			FAILURE.... DIAGONAL TENSION				

BEAM No. 333.2 MIXTURE 1-2-4 AGE 33 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.04	.0035	.0041	.0037	.0039	.0000417	.0000498	.456
2000	0.05	.0078	.0086	.0080	.0087	.0000931	.0001108	.457
3000	0.09	.0164	.0180	.0161	.0168	.0001990	.0002230	.472
4000	0.13	.0279	.0313	.0277	.0310	.0003340	.0003930	.460
5000	0.14	.0408	.0406	.0407	.0451	.0004900	.0005700	.462
6000	0.23	.0540	.0660	.0548	.0622	.0006320	.0008040	.440
7000	0.32	.0729	.0864	.0702	.0802	.0008770	.0010110	.464
8000	0.43	.0973	.1151	.0753	.1005	.0012110	.0012310	.496
9000	0.63	.1433	.1694	.890	.1471	.0017900	.0017900	.500
9040	MAXIMUM		FAILURE..... TENSION					

BEAM No. 333.1 MIXTURE 1-2-4 AGE 17 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.04	.0062	.0070	.0057	.0066	.000076	.000082	.482
2000	0.08	.0148	.0139	.0143	.0162	.000179	.000204	.468
3000	0.13	.0222	.0198	.0218	.0248	.000265	.000315	.457
4000	0.18	.0309	.0278	.0250	.0342	.000371	.000432	.462
5000	0.25	.0450	.0422	.0418	.0474	.000555	.000585	.487
6000	0.35	.0687	.0666	.0592	.0670	.000880	.000797	.525
7000	0.50	.1077	.1056	.0832	.1061	.001372	.001268	.520
7500	MAXIMUM			FAILURE ..... DIAGONAL TENSION				

BEAM No. 334.1 MIXTURE 1-2-4 AGE 28 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0023	.0027	.0041	.0041	.000010	.000025	.304
2000	0.05	.0059	.0063	.0084	.0093	.000067	.000115	.367
3000	0.08	.0116	.0111	.0143	.0158	.000121	.000192	.385
4000	0.12	.0180	.0188	.0225	.0246	.000215	.000294	.422
5000	0.16	.0260	.0269	.0327	.0353	.000308	.000438	.413
6000	0.22	.0344	.0362	.0445	.0475	.000407	.000588	.409
7000	0.27	.0422	.0439	.0546	.0580	.000490	.000725	.403
8000	0.32	.0512	.0532	.0659	.0700	.000595	.000875	.405
9000	0.39	.0593	.0618	.0769	.0815	.000690	.001024	.403
10000	0.44	.0690	.0714	.0870	.0940	.000808	.001146	.413
10680	0.48							
11000	0.50	.0770	.0793	.0966	.1015	.000898	.001275	.413
11800	0.57 MAXIMUM			FAILURE .... TENSION				.410

BEAM No. 334.2 MIXTURE 1-2-4. AGE 30 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.08	.0038	.0013	.0021	.0020	.000060	.000013	.826
2000	0.09	.0094	.0014	.0049	.0049	.000147	.000028	.832
3000	0.11	.0141	.0017	.0078	.0078	.000220	.000054	.802
4000	0.15	.0201	.0101	.0082	.0136	.000294	.000122	.707
5000	0.20	.0282	.0188	.0228	.0231	.000388	.000241	.613
6000	0.26	.0367	.0278	.0336	.0337	.000492	.000380	.564
7000	0.32	.0455	.0367	.0441	.0442	.000592	.000508	.530
8000	0.39	.0546	.0464	.0545	.0547	.000695	.000650	.512
9000	0.41	.0649	.0552	.0659	.0659	.000820	.000800	.505
10000	0.44	.0737	.0562	.0758	.0759	.000925	.000925	.500
11000	0.60	.0832	.0655	.0865	.0867	.001035	.001062	.493
11300	0.60	MAXIMUM			FAILURE .... TENSION			
10700	0.66	.0902	.0712	.0921	.0933	.001130	.001132	.499
9000	1.03	.1678	.1613	.1941	.2206	.001865	.002740	.406
10100	1.85	.						

BEAM No. 334.3 MIXTURE 1-2-4 AGE 33 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0039	.0036	.0031	.0031	.000051	.000034	.602
2000	0.05	.0093	~~.0146~~	.0078	.0077	.000127	.000082	.607
3000	0.08	.0164	.0167	.0145	.0147	.000221	.000163	.575
4000	0.12	.0249	.0239	.0232	.0232	.000325	.000269	.547
5000	0.19	.0380	.0362	.0373	.0378	.000483	.000449	.518
6000	0.26	.0519	.0559	.0509	.0523	.000658	.000620	.515
7000	0.34	.0673	.0665	.0657	.0669	.000868	.000761	.530
8000	0.43	.0866	.0855	.0821	.0846	.001100	.000982	.528
8400	0.48							-
9000	0.54	.1013	.1097	.1017	.1029	.001362	.001210	.528
9800	0.74	MAXIMUM			FAILURE .... TENSION			-
8000	1.06	.2909	.2849	.2584	.2605	.003820	.002910	.563

BEAM No. 331.2 MIXTURE ....1-2-4 AGE...58 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.01	.0031	.0029	.0024	.0024	.000041	.000025	.624
2000	0.04	.0058	.0065	.0052	.0057	.000082	.000061	.573
3000	0.06	.0115	.0115	.0102	.0100	.000154	.000113	.576
4000	0.08	.0179	.0180	.0175	.0167	.000232	.000202	.534
5000	0.12	.0259	.0262	.0271	.0265	.000325	.000329	.496
6000	0.18	.0344	.0354	.0388	.0377	.000430	.000493	.466
7000	0.23	.0431	.0444	.0498	.0482	.000522	.000622	.456
8000	0.28	.0519	.0540	.0611	.0589	.000622	.000780	.445
9000	0.33	.0602	.0633	.0711	.0684	.000725	.000900	.450
10000	0.38	.0693	.0730	.0818	.0788	.000850	.001050	.450
11000	0.44	.0793	.0833	.0931	.0896	.000965	.001190	.450
12000	0.50	.0910	.0955	.1134	.1076	.001060	.001470	.429
11500	0.61	.1159	.1193	.1553	.1518	.001260	.002080	.378
				FAILURE ..... TENSION.				

BEAM No. 335.1 MIXTURE.....1-2-4 AGE..... 62 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.01	.0039	.0035	.0030	.0035	.000050	.000036	.584
2000	0.03	.0082	.0076	.0075	.0079	.000101	.000092	.525
3000	0.06	.0128	.0122	.0125	.0129	.000156	.000154	.504
4000	0.09	.0178	.0170	.0181	.0184	.000215	.000225	.489
5000	0.11	.0234	.0224	.0242	.0247	.000280	.000304	.479
6000	0.15	.0303	.0290	.0326	.0332	.000355	.000416	.460
7000	0.21	.0386	.0372	.0435	.0436	.000448	.000575	.440
8000	0.25	.0461	.0446	.0534	.0535	.000525	.000700	.422
9000	0.31	.0542	.0537	.0640	.0640	.000602	.000852	.420
10000	0.36	.0631	.0614	.0748	.0749	.000700	.001002	.415
11000	0.41	.0707	.0688	.0843	.0844	.000785	.001150	.411
11800		MAXIMUM		FAILURE ..... TENSION.				
11000	0.60	.1082	.1082	.1543	.1541	.001082	.002160	.334

BEAM NO. 335.2 MIXTURE ..... 1-2-4 AGE ..... 69 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0027	.0029	.0022	.0023	.000039	.000023	.632
2000	0.04	.0069	.0071	.0052	.0059	.000097	.000059	.624
3000	0.07	.0119	.0120	.0100	.0107	.000162	.000113	.590
4000	0.09	.0177	.0175	.0163	.0165	.000230	.000191	.547
5000	0.15	.0266	.0255	.0268	.0264	.000325	.000325	.500
6000	0.20	.0351	.0331	.0371	.0362	.000417	.000455	.478
7000	0.25	.0436	.0405	.0473	.0460	.000502	.000600	.462
8000	0.30	.0523	.0482	.0577	.0556	.000598	.000730	.452
9000	0.36	.0612	.0563	.0674	.0646	.000698	.000852	.456
10000	0.41	.0703	.0643	.0773	.0739	.000798	.000980	.452
11000	0.47	.0805	.0722	.0869	.0836	.000930	.001170	.461
11200	MAXIMUM.			FAILURE ..... TENSION.				
10800	0.83	.1278	.1023	.1420	.1437	.001425	.002120	.402

BEAM NO. 322.5 MIXTURE ... 1-2-4. AGE ..... 383 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.05	.0041	.0042	.0050	.0050	.000046	.000066	.412
2000	0.08	.0098	.0097	.0119	.0121	.000111	.000160	.410
3000	0.13	.0153	.0150	.0183	.0194	.000171	.000250	.406
4000	0.19	.0209	.0208	.0252	.0270	.000233	.000291	.400
5000	0.22	.0266	.0264	.0321	.0348	.000293	.000445	.397
6000	0.26	.0323	.0322	.0388	.0425	.000358	.000541	.398
7000	0.33	.0376	.0375	.0454	.0498	.000415	.000638	.394
8000	0.36	.0432	.0430	.0519	.0573	.000475	.000731	.394
9000	0.38	.0488	.0487	.0586	.0646	.000540	.000821	.397
10200	0.41	.0577	.0588	.0692	.0765	.000649	.000970	.401
11000	0.44	.0644	.0645	.0778	.0858	.000709	.001094	.393
12000	0.48	.0701	.0702	.0848	.0940	.000769	.001203	.390
12300	MAXIMUM.			FAILURE ..... TENSION.				
10000	0.58	.0853	.0840	.1312	.1396	.000758	.001972	.281

Beam No. 322.6 Mixture... 1-2-4 Age... 383 Days.

Applied Load Lb.	Deflection In.	Extensometer Readings In. 1	3	2	4	Unit Deformation Upper Fiber	Steel	Neutral Axis "k"
1000	0.02	.0031	.0038	.0036	.0038	.000043	.000046	.485
2000	0.05	.0073	.0000	.0107	.0107	.000088	.000145	.378
3000	0.10	.0144	.0175	.0206	.0209	.000173	.000281	.377
4000	0.15	.0209	.0253	.0309	.0314	.000243	.000427	.363
5000	0.20	.0293	.0328	.0407	.0414	.000333	.000558	.374
6000	0.26	.0367	.0405	.0505	.0518	.000412	.000696	.372
7000	0.31	.0439	.0481	.0602	.0615	.000490	.000827	.372
8000	0.36	.0509	.0555	.0692	.0713	.000568	.000955	.373
9000	0.40	.0508	.0629	.0782	.0808	.000648	.001080	.375
10000	0.45	.0650	.0703	.0877	.0904	.000725	.001208	.375
11000	0.51	.0726	.0783	.0979	.1009	.000808	.001352	.374
11300	Maximum.			Failure.... Tension.				
11000	0.58	.0867	.0935	.1289	.1330	.000886	.001840	.325
10450	0.68							
10000	1.11							

Beam No. 351.2 Mixture... 1-4-8 Age... 14 Days.

Applied Load Lb.	Deflection In.	Extensometer Readings In. 1	3	2	4	Unit Deformation Upper Fiber	Steel	Neutral Axis "k"
1000	0.05	.0084	.0006	.0088	.0082	.000105	.000103	.505
2000	0.11	.0192	Failed To Work Reset	.0188	.0176	.000244	.000208	.539
3000	0.21	.0366	.0171	.0325	.0316	.000492	.000356	.580
3340	Maximum.			Failure..... Diagonal Tension				

BEAM NO. 352.1 MIXTURE... 1-4-8 AGE... 62 DAYS.

Applied Load Lb	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0048	.0048	.0047	.0044	.000062	.000054	.533
2000	0.05	.0100	.0102	.0103	.0095	.000129	.000118	.522
3000	0.09	.0164	.0173	.0186	.0172	.000206	.000223	.480
4000	0.14	.0234	.0257	.0283	.0265	.000294	.000349	.457
4500	0.17	.0272	.0309	.0338	.0320	.000342	.000422	.448
5000	0.19	.0300	.0347	.0376	.0360	.000382	.000471	.448
5500	0.22	.0337	.0395	.0425	.0409	.000431	.000536	.446
6000	0.25	.0374	.0450	.0479	.0466	.000486	.000601	.445
6500	0.28	.0413	.0497	.0528	.0515	.000535	.000693	.445
7000	0.31	.0456	.0550	.0577	.0569	.000582	.000750	.441
7500	0.35	.0504	.0604	.0629	.0612	.000650	.000800	.456
8000	0.39	.0562	.0673	.0689	.0689	.000725	.000882	.458
8500	0.43	.0609	.0722	.0732	.0739	.000798	.000929	.462
9000	0.47	.0664	.0790	.0789	.0799	.000880	.001020	.467
9100	MAXIMUM.			FAILURE... DIAGONAL TENSION.				

BEAM NO. 352.2 MIXTURE... 1-4-8 AGE... 65 DAYS.

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "k"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	~~.0039~~	.0054	.0055	~~.0043~~	.000068	.000067	.504
2000	0.06	~~.0149~~	.0133	.0152	~~.0136~~	.000157	.000194	.447
3000	0.11	~~.0243~~	.0221	.0251	~~.0232~~	.000261	.000322	.448
4000	0.17	~~.0345~~	.0316	.0369	~~.0331~~	.000368	.000480	.434
5000	0.22	~~.0460~~	.0422	.0488	~~.0434~~	.000494	.000623	.440
6000	0.29	~~.0588~~	.0545	.0615	~~.0543~~	.000648	.000786	.452
7000	0.38	~~.0737~~	.0687	.0750	~~.0656~~	.000830	.000944	.468
7400	MAXIMUM.			FAILURE.... DIAGONAL TENSION.				

BEAM No. 362.2 MIXTURE 1-5-10 AGE 68 DAYS

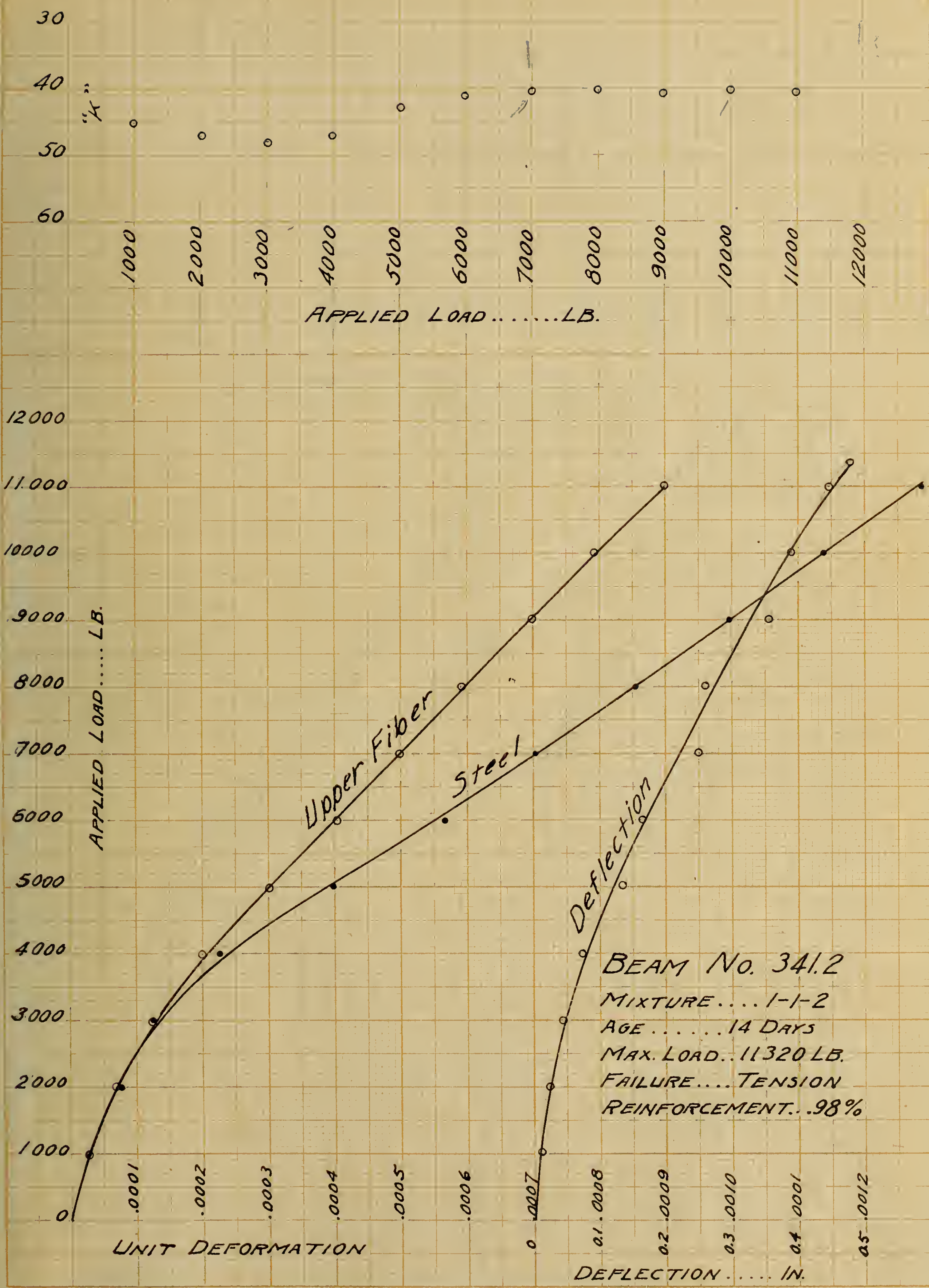
Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.05	.0077	.0148	.0064	.0026	.000092	.000108	.457
2000	0.10	.0198	.0198	.0173	.0211	.000243	.000262	.481
3000	0.20	.0367	.0375	.0225	.0362	.000468	.000432	.520
4000	0.34	.0654	.0692	.0313	.0574	.000876	.000642	.578
4300	MAXIMUM		FAILURE.... DIAGONAL TENSION					

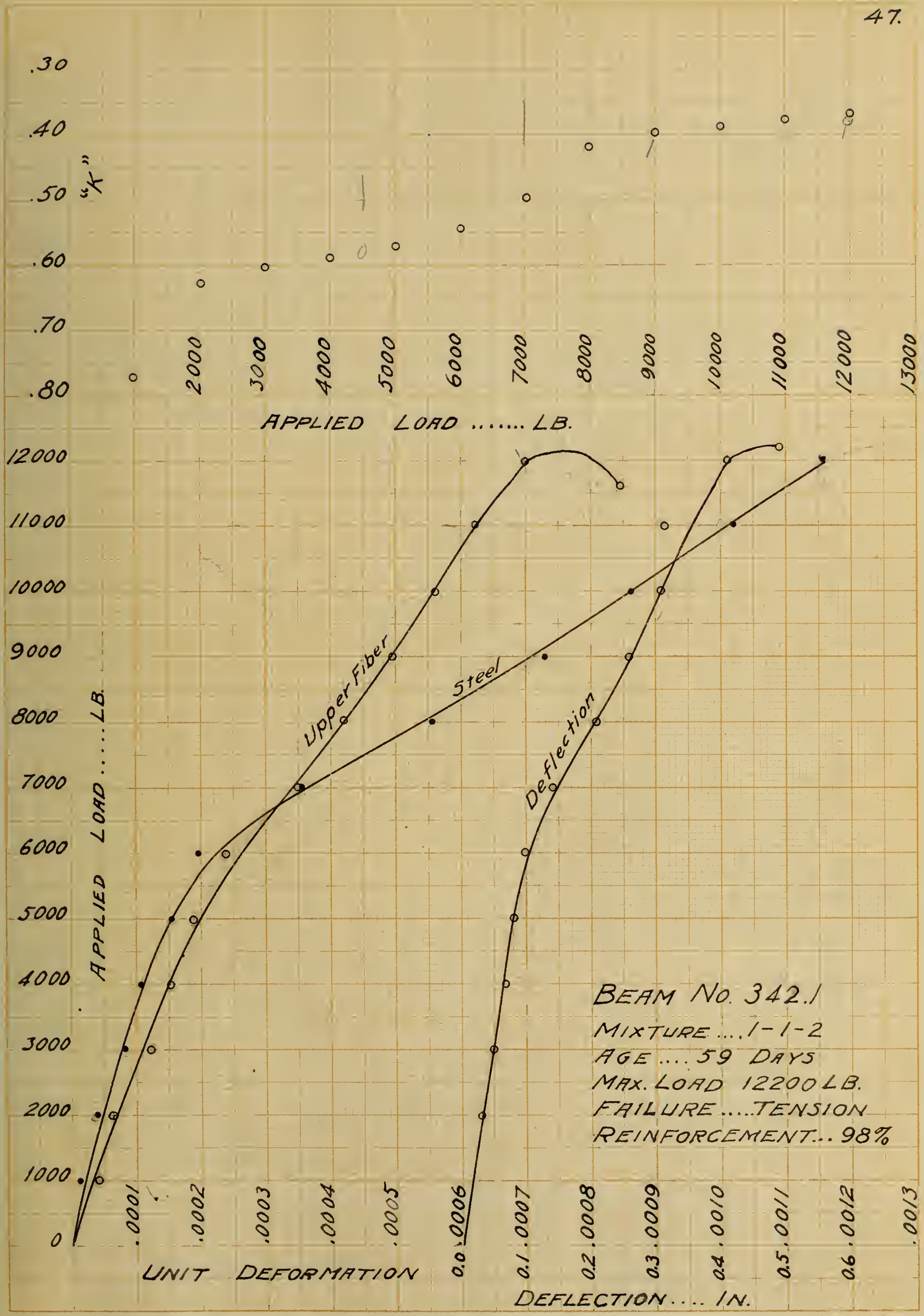
BEAM No. 361.1 MIXTURE 1-5-10 AGE 66 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.03	.0077	.0080	.0049	.0055	.000114	.000046	.713
2000	0.09	.0177	.0189	.0141	.0149	.000255	.000150	.630
3000	0.15	.0288	.0310	.0250	.0259	.000409	.000269	.603
4000	0.21	.0405	.0439	.0362	.0380	.000570	.000422	.572
5000	0.29	.0534	.0574	.0480	.0501	.000740	.000538	.575
6000	0.36	.0658	.0711	.0594	.0595	.000920	.000661	.582
6500	0.40	.0723	.0784	.0652	.0656	.001060	.000980	.598
6800	MAXIMUM			FAILURE.... DIAGONAL TENSION				

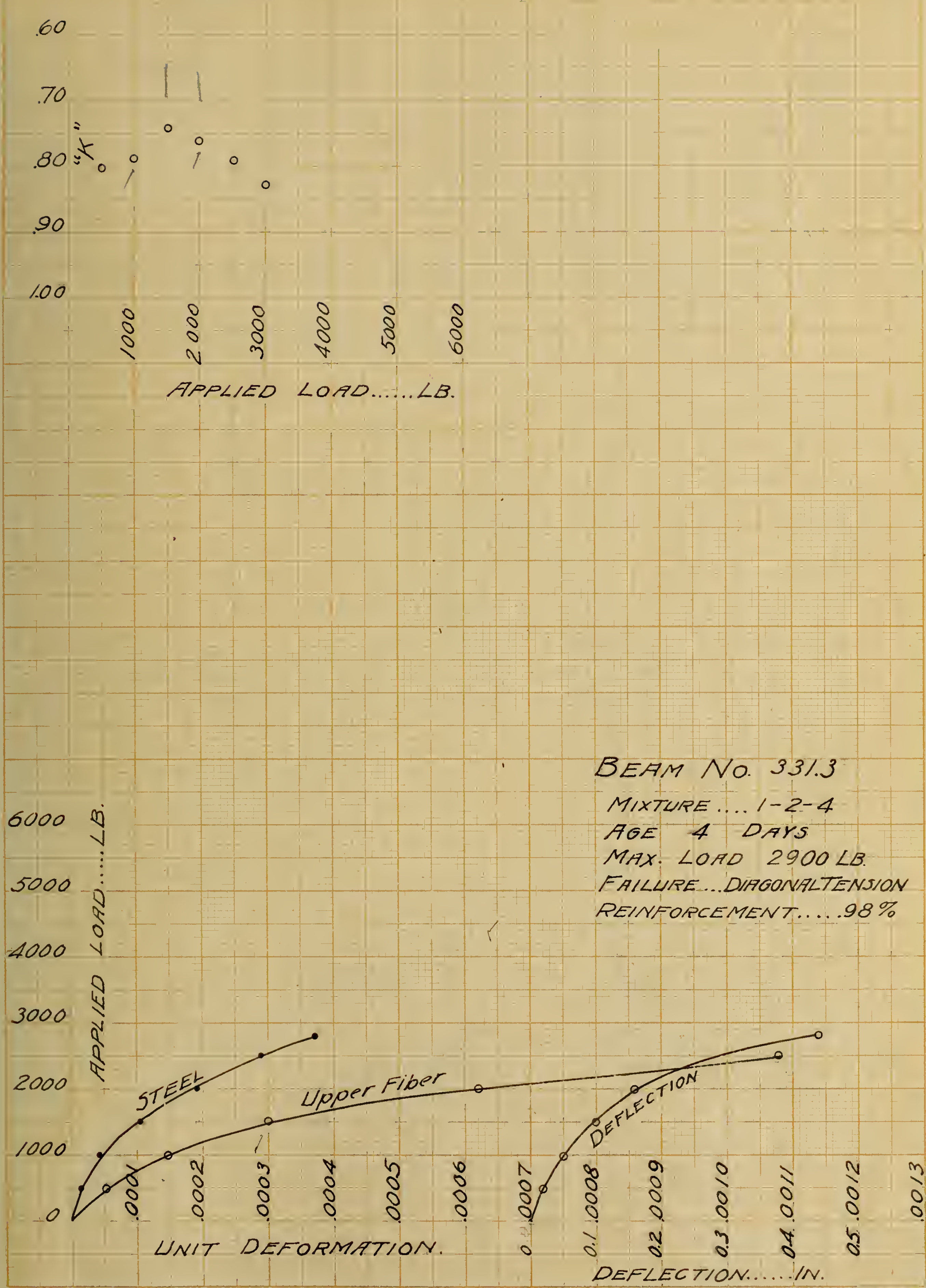
BEAM No. 362.1 MIXTURE 1-5-10 AGE 67 DAYS

Applied Load Lb.	Deflection In.	Extensometer Readings In.				Unit Deformation		Neutral Axis "K"
		1	3	2	4	Upper Fiber	Steel	
1000	0.02	.0042	.0039	.0035	.0041	.000050	.000046	.524
2000	0.06	.0109	.0109	.0105	.0107	.000140	.000126	.526
3000	0.11	.0194	.0208	.0209	.0201	.000265	.000245	.520
4000	0.16	.0288	.0315	.0326	.0316	.000395	.000392	.502
5000	0.21	.0296	.0410	.0420	.0414	.000515	.000509	.503
6000	0.28	.0397	.0520	.0526	.0527	.000654	.000639	.506
6500	0.32	.0448	.0577	.0574	.0582	.000730	.000696	.512
6700	MAXIMUM			FAILURE.... DIAGONAL TENSION				

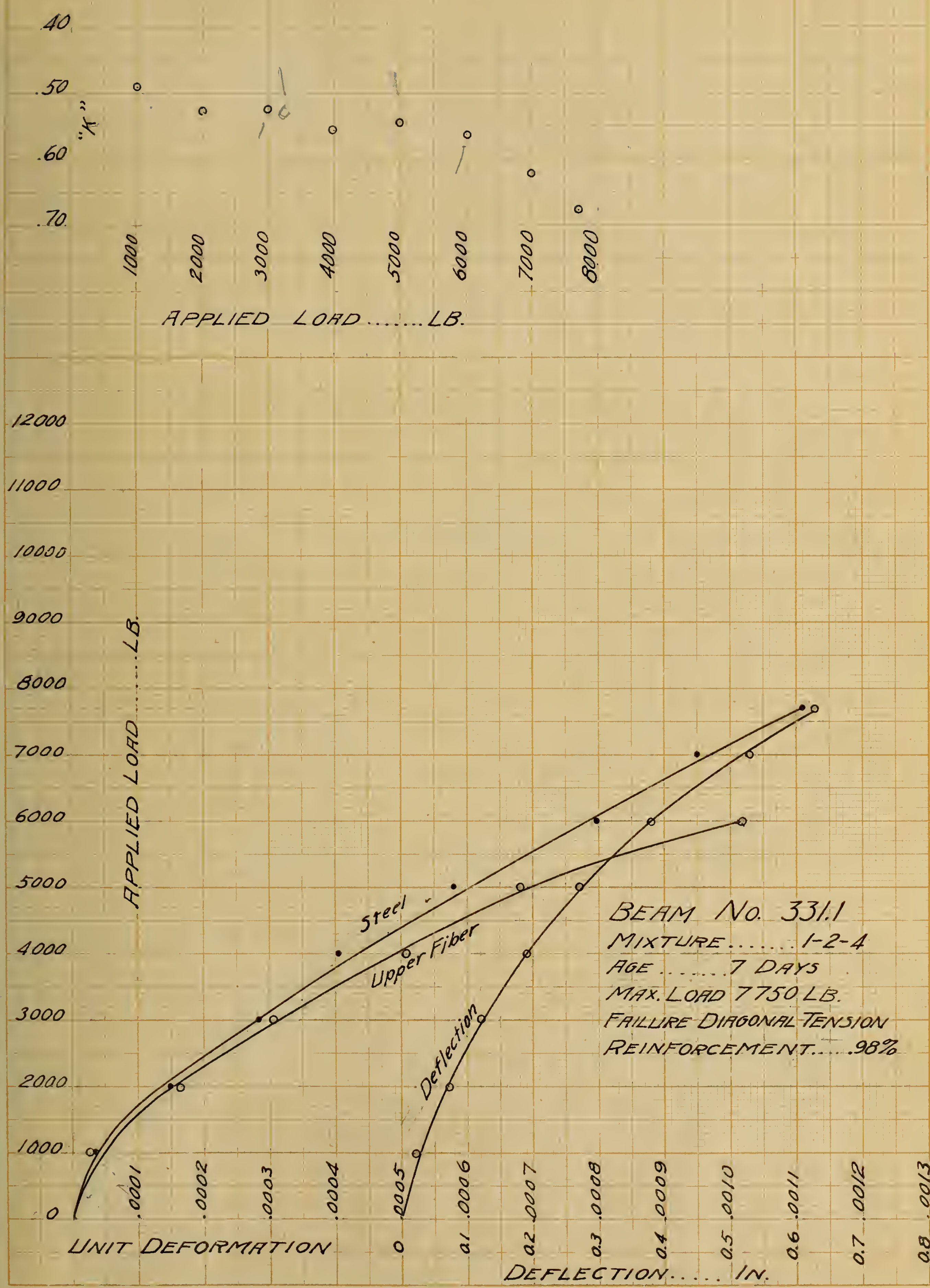

"k"
30
40
50
60
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD......LB.
APPLIED LOAD.....LB.
12000
11.000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0001
.0012
0
0.1
0.2
0.3
0.4
0.5
Upper Fiber
Steel
Deflection
UNIT DEFORMATION
DEFLECTION..... IN.
BEAM NO. 341.2
MIXTURE.... 1-1-2
AGE...... 14 DAYS
MAX. LOAD.. 11320 LB.
FAILURE.... TENSION
REINFORCEMENT.. .98%

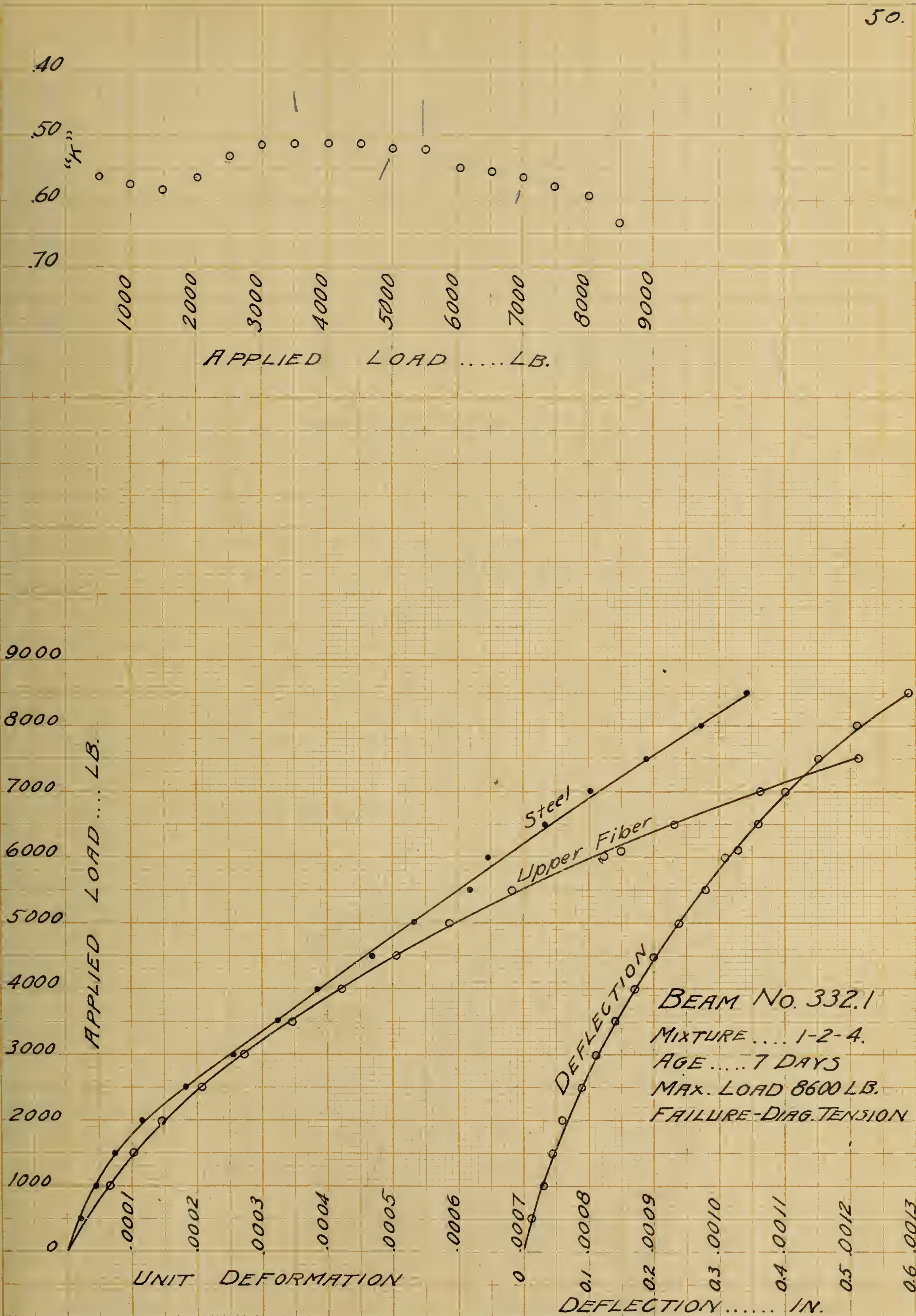


"K"
.30
.40
.50
.60
.70
.80
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
APPLIED LOAD ...... LB.
APPLIED LOAD ..... LB.
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
Upper Fiber
Steel
Deflection
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
0.0
0.1
0.2
0.3
0.4
0.5
0.6
UNIT DEFORMATION
DEFLECTION .... IN.
BEAM No. 342.1
MIXTURE 1-1-2
AGE .... 59 DAYS
MAX. LOAD 12200 LB.
FAILURE ....TENSION
REINFORCEMENT... 98%

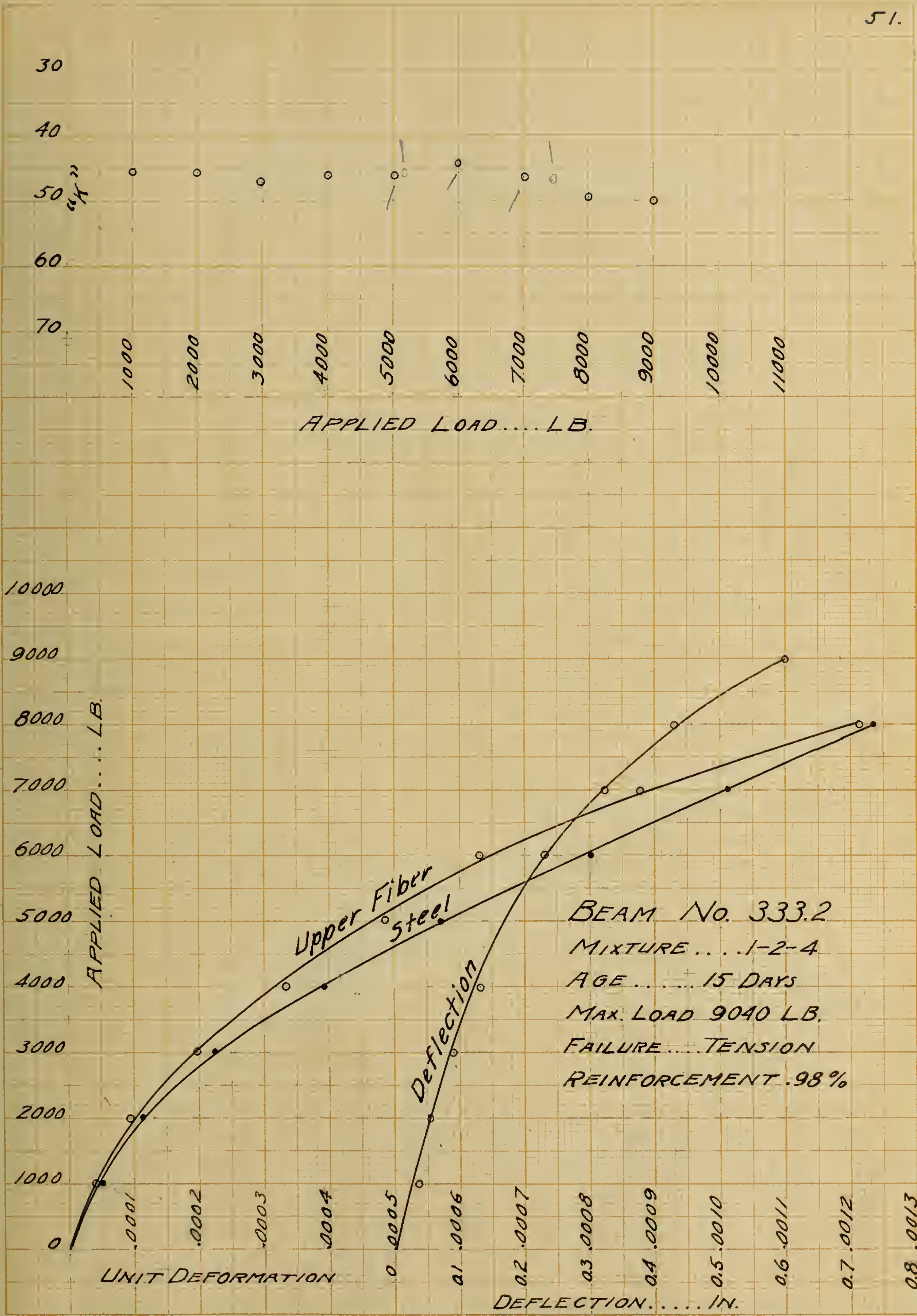


"K"
.60
.70
.80
.90
1.00
1000
2000
3000
4000
5000
6000
APPLIED LOAD.....LB.
BEAM NO. 331.3
MIXTURE 1-2-4
AGE 4 DAYS
MAX. LOAD 2900 LB.
FAILURE ... DIAGONAL TENSION
REINFORCEMENT.....98%
APPLIED LOAD.....LB.
6000
5000
4000
3000
2000
1000
0
STEEL
Upper Fiber
DEFLECTION
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
0
0.1
0.2
0.3
0.4
0.5
UNIT DEFORMATION.
DEFLECTION.....IN.

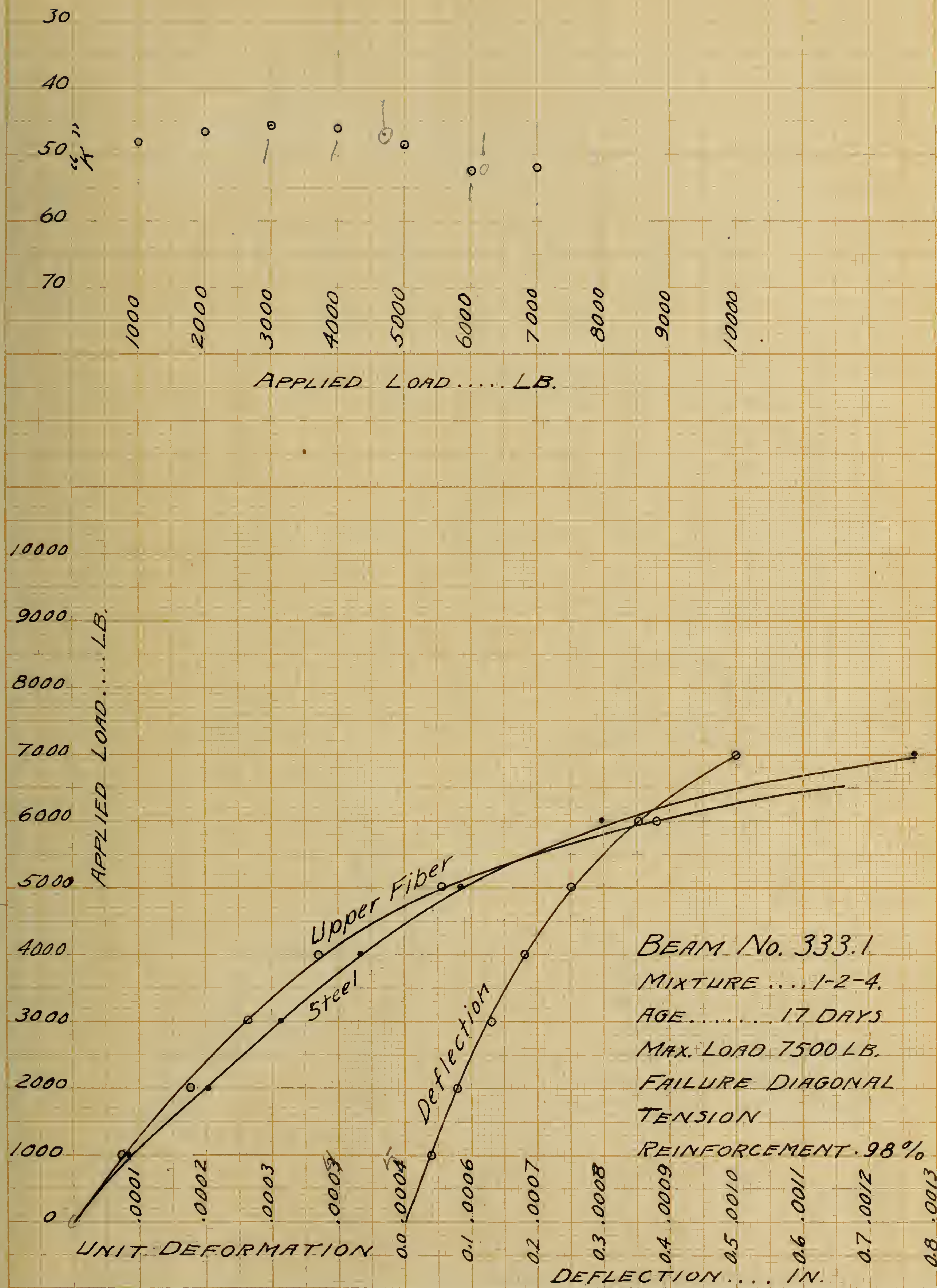

.40
.50
.60
.70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
APPLIED LOAD.......LB.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD.......LB.
Steel
Upper Fiber
Deflection
BEAM No. 331.1
MIXTURE.......1-2-4
AGE.......7 DAYS
MAX. LOAD 7750 LB.
FAILURE DIAGONAL TENSION
REINFORCEMENT.....98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
DEFLECTION..... IN.



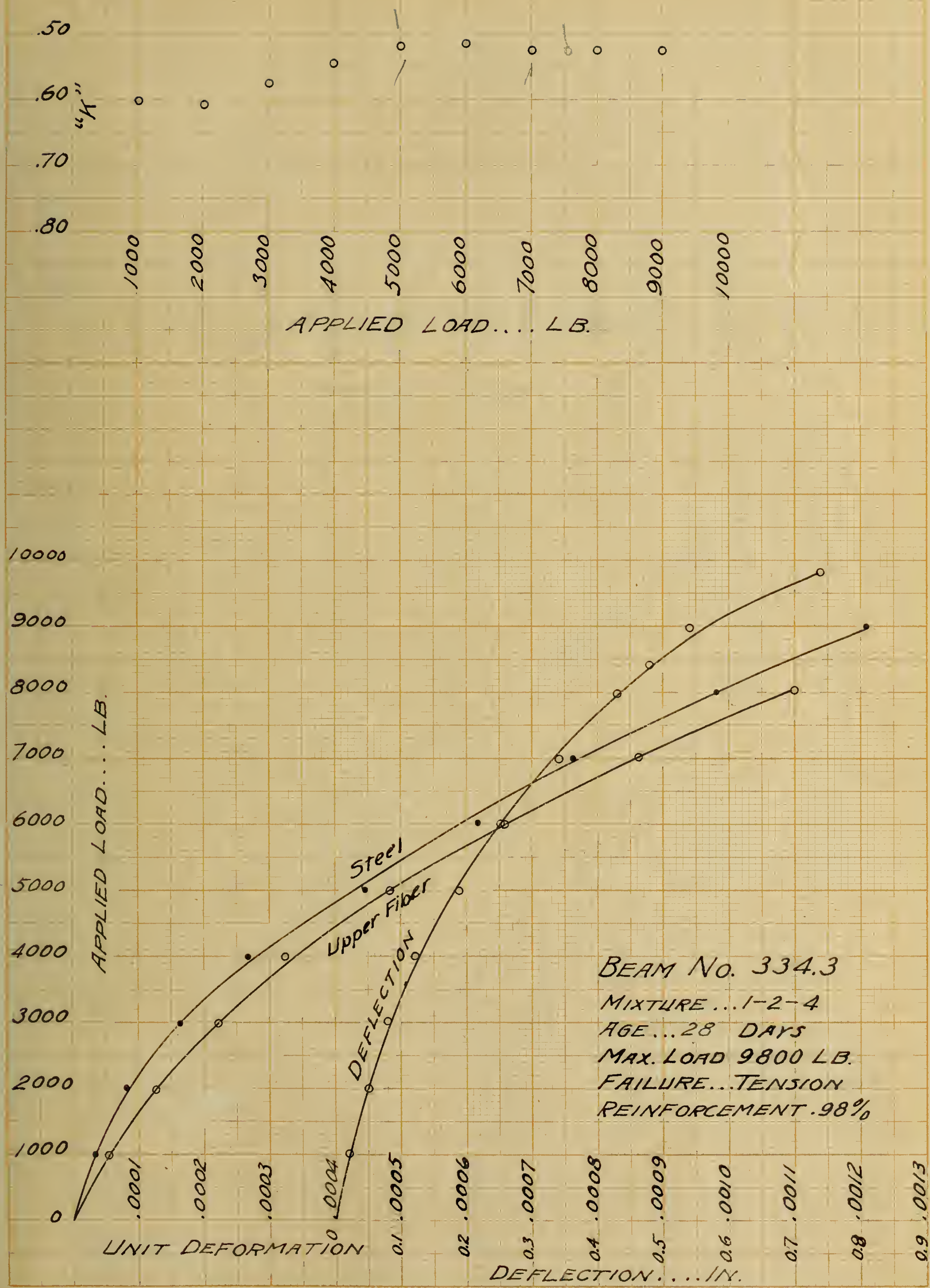
.40
.50
.60
.70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
APPLIED LOAD .....LB.
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD ... LB.
Steel
Upper Fiber
DEFLECTION
BEAM NO. 332.1
MIXTURE .... 1-2-4.
AGE .....7 DAYS
MAX. LOAD 8600 LB.
FAILURE-DIAG. TENSION
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION ...... IN.



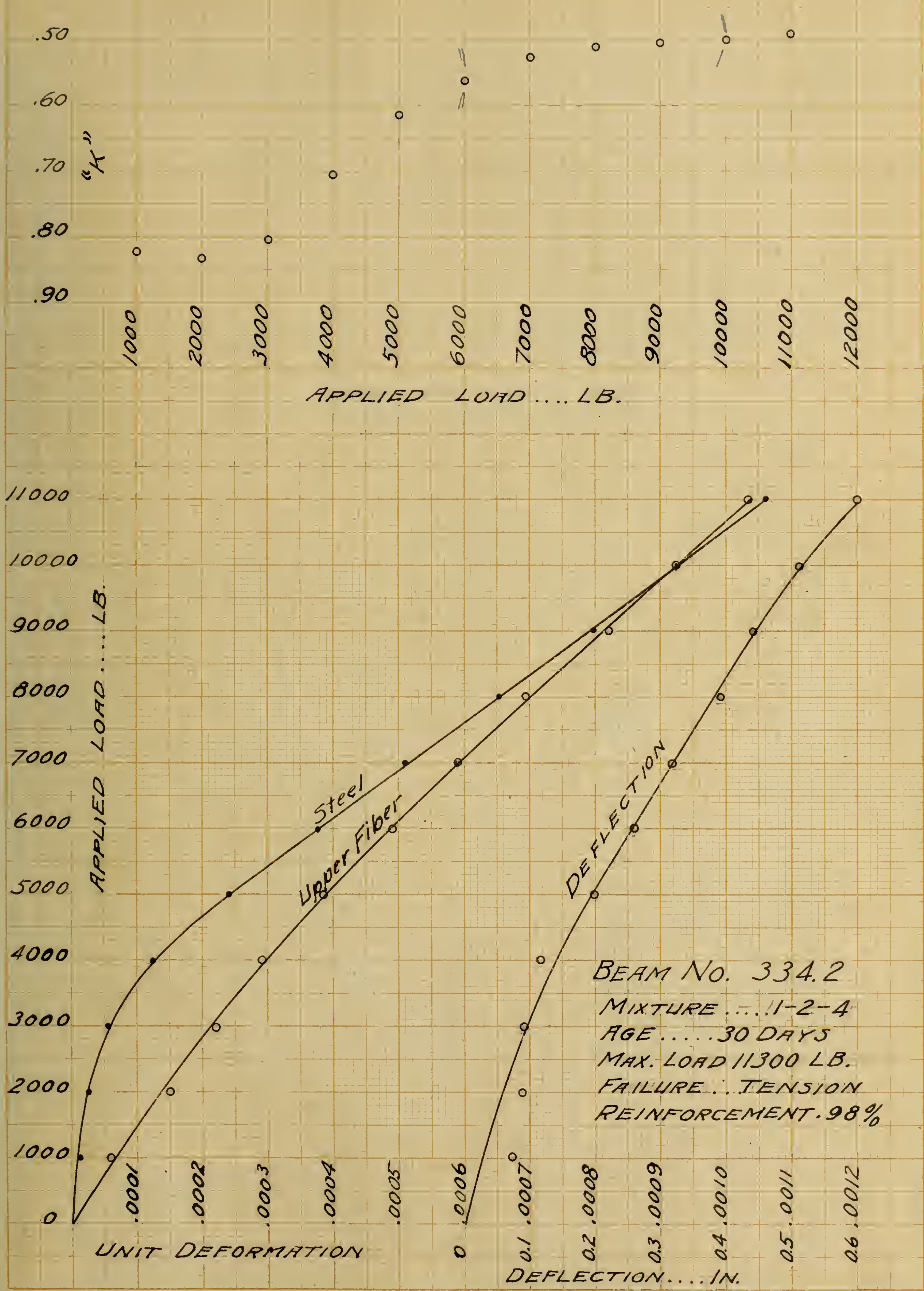
30
40
50
60
70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
APPLIED LOAD.... LB.
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD.... LB.
Upper Fiber
Steel
Deflection
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
DEFLECTION..... IN.
BEAM No. 333.2
MIXTURE....1-2-4
AGE........15 DAYS
MAX. LOAD 9040 LB.
FAILURE.....TENSION
REINFORCEMENT .98%



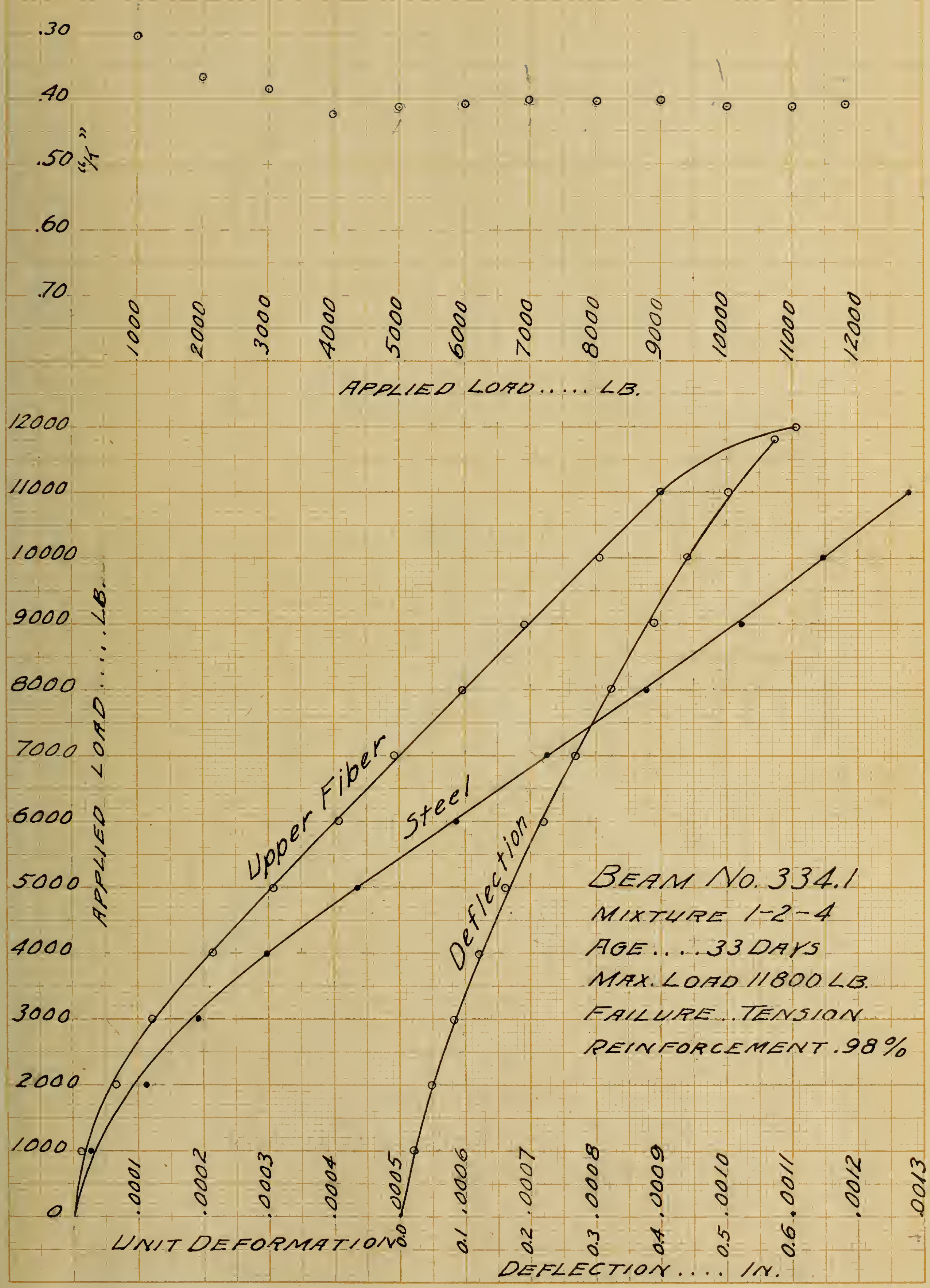
30
40
50
60
70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
APPLIED LOAD.... LB.
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD.... LB.
Upper Fiber
Steel
Deflection
.0001
.0002
.0003
.0005
.0004
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
DEFLECTION.... IN.
BEAM No. 333.1
MIXTURE ....1-2-4.
AGE........17 DAYS
MAX. LOAD 7500 LB.
FAILURE DIAGONAL
TENSION
REINFORCEMENT .98%



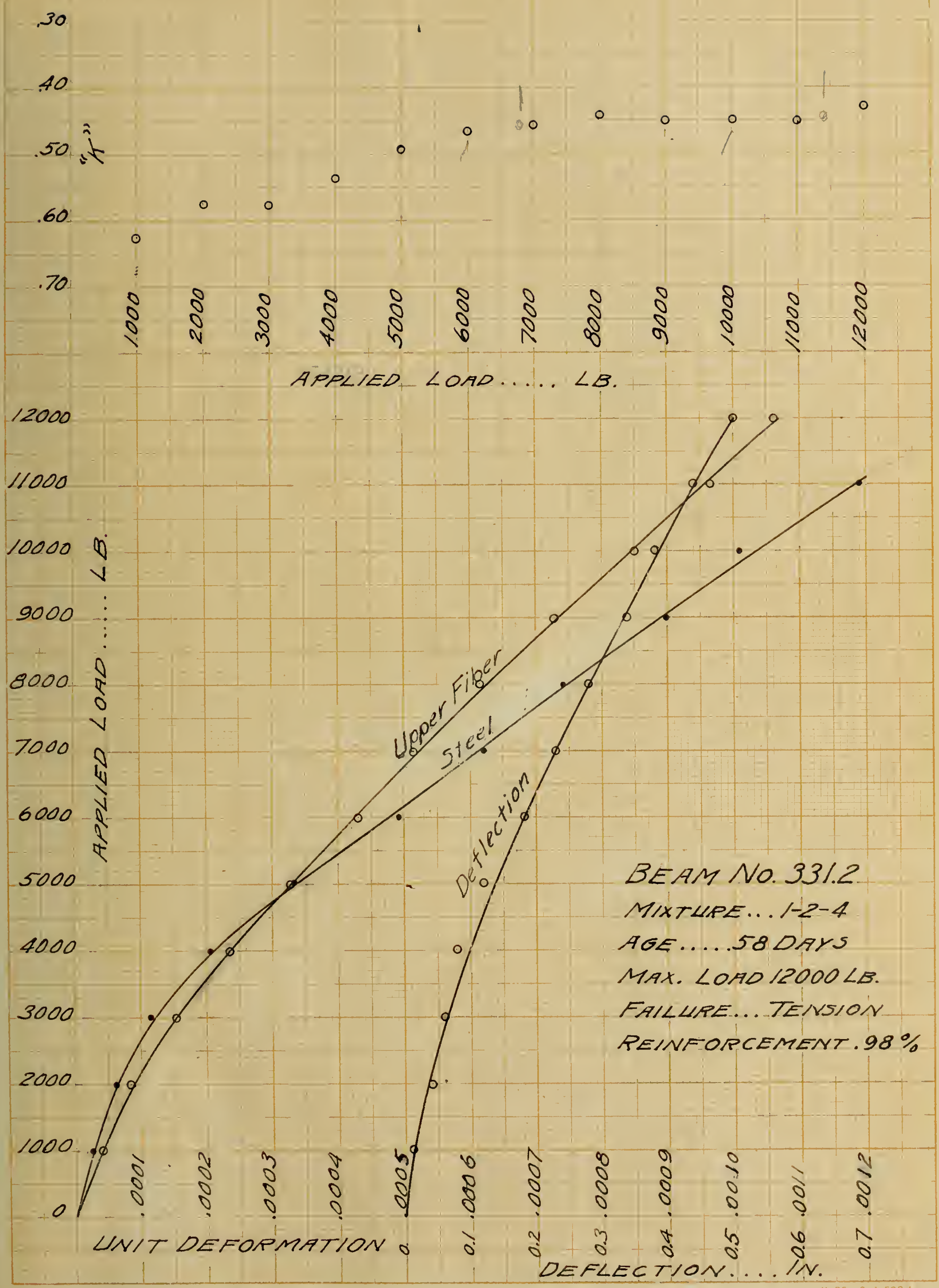
.50
.60
.70
.80
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
APPLIED LOAD.... LB.
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD.... LB.
Steel
Upper Fiber
DEFLECTION
BEAM NO. 334.3
MIXTURE...1-2-4
AGE...28 DAYS
MAX. LOAD 9800 LB.
FAILURE...TENSION
REINFORCEMENT .98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
DEFLECTION....IN.

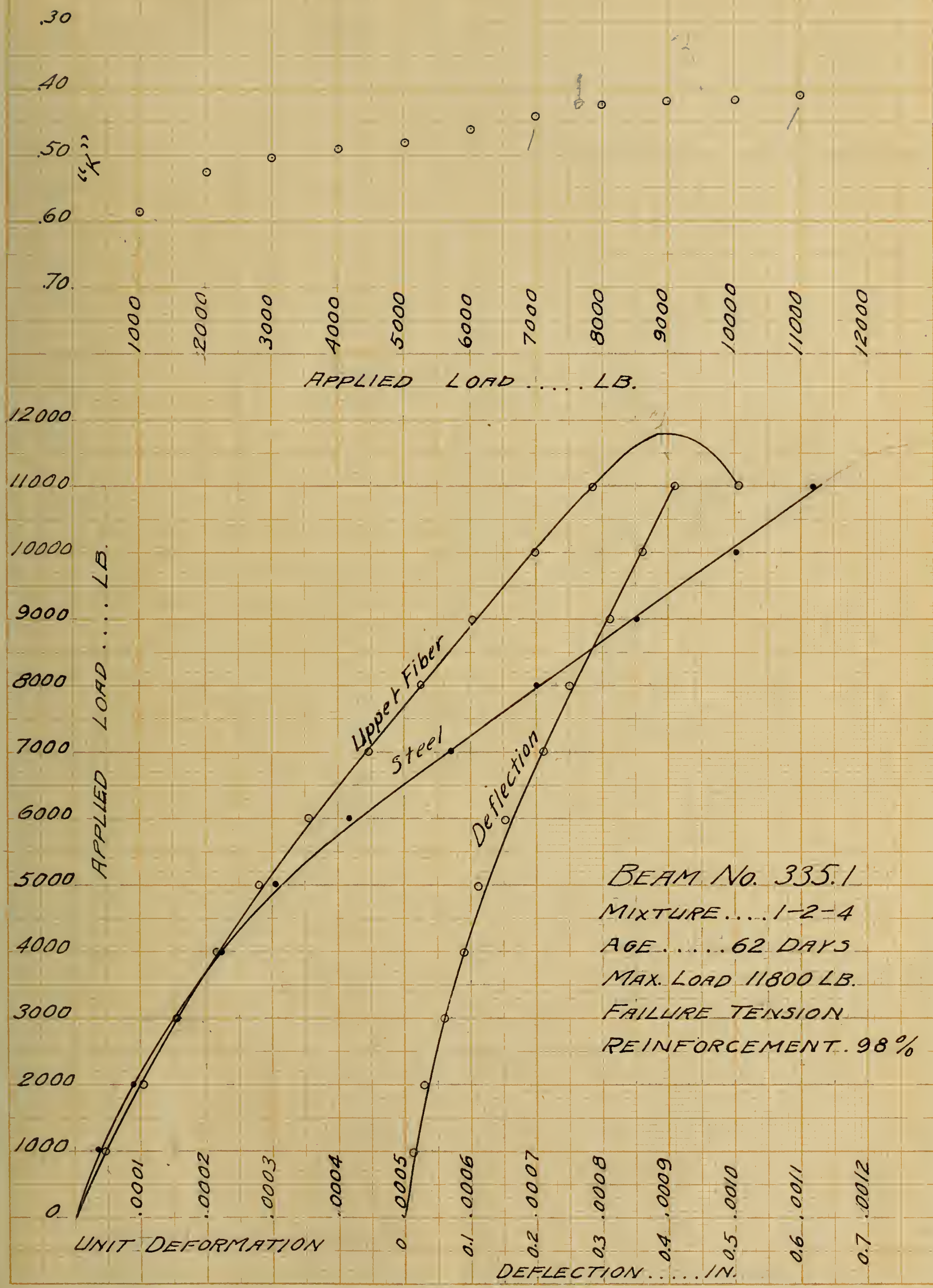


.50
.60
.70
.80
.90
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD.... LB.
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
.0
APPLIED LOAD.... LB.
Steel
Upper Fiber
DEFLECTION
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION.... IN.
BEAM NO. 334.2
MIXTURE 1-2-4
AGE ..... 30 DAYS
MAX. LOAD 11300 LB.
FAILURE... TENSION
REINFORCEMENT .98%

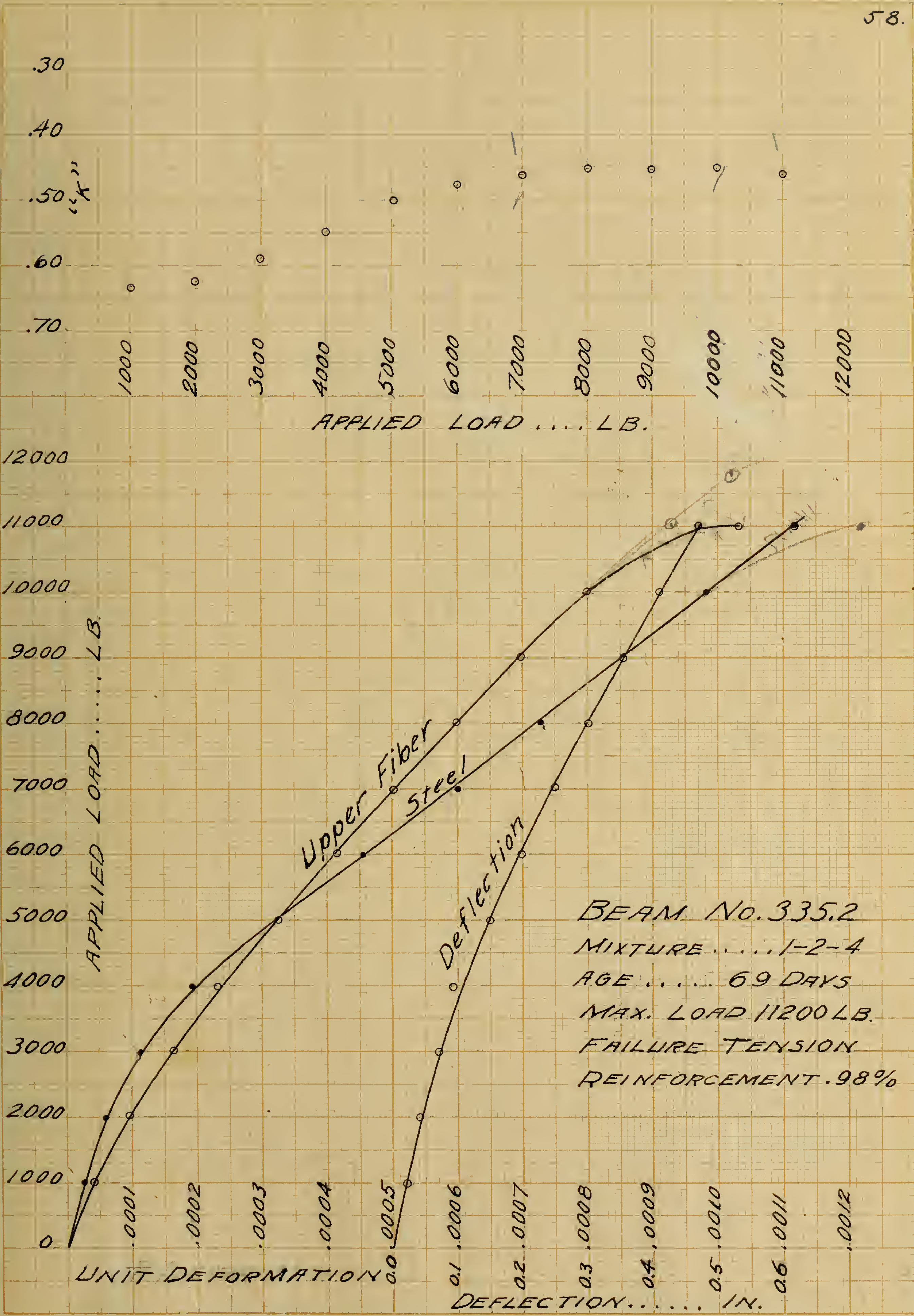


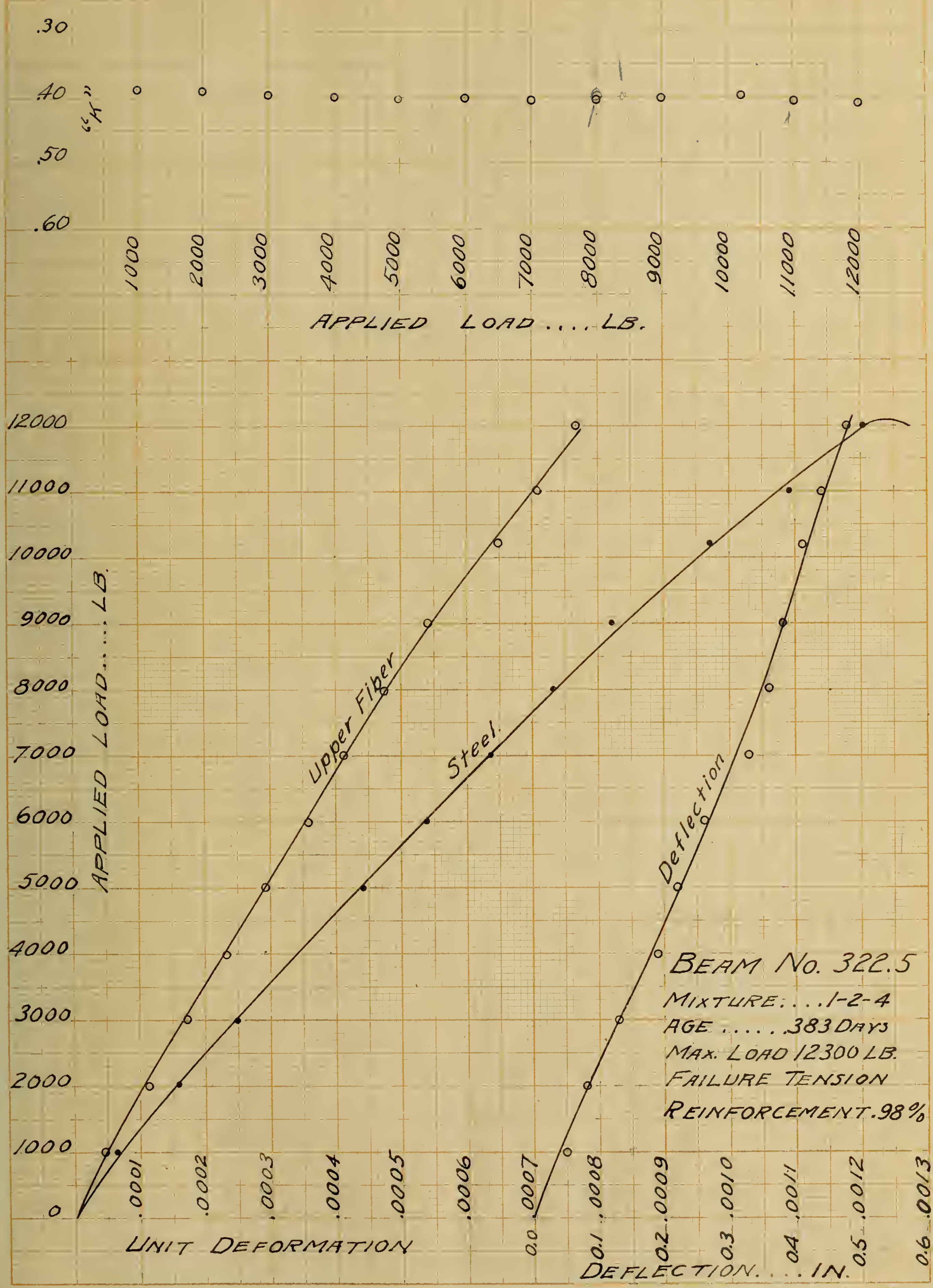
.30
.40
.50
.60
.70
"k"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD..... LB.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD..... LB.
Upper Fiber
Steel
Deflection
BEAM No. 334.1
MIXTURE 1-2-4
AGE....33 DAYS
MAX. LOAD 11800 LB.
FAILURE..TENSION
REINFORCEMENT .98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION.... IN.


"k"
.30
.40
.50
.60
.70
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD..... LB.
APPLIED LOAD..... LB.
Upper Fiber
Steel
Deflection
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
DEFLECTION.... IN.
BEAM No. 331.2
MIXTURE... 1-2-4
AGE..... 58 DAYS
MAX. LOAD 12000 LB.
FAILURE... TENSION
REINFORCEMENT .98%

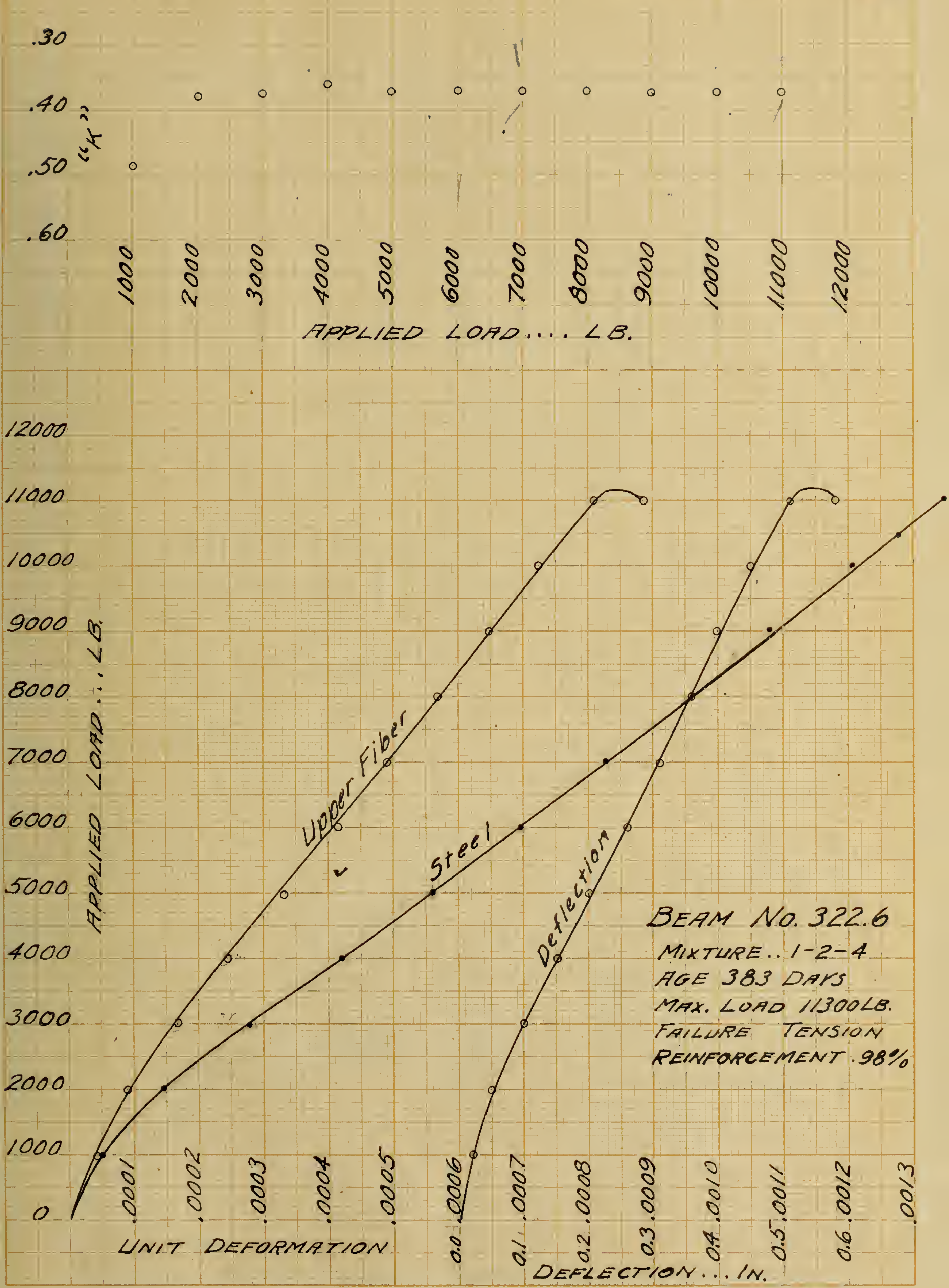


.30
.40
.50
.60
.70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD.....LB.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD.... LB.
Upper Fiber
Steel
Deflection
BEAM No. 335.1
MIXTURE....1-2-4
AGE.......62 DAYS
MAX. LOAD 11800 LB.
FAILURE TENSION
REINFORCEMENT. 98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
DEFLECTION.....IN.

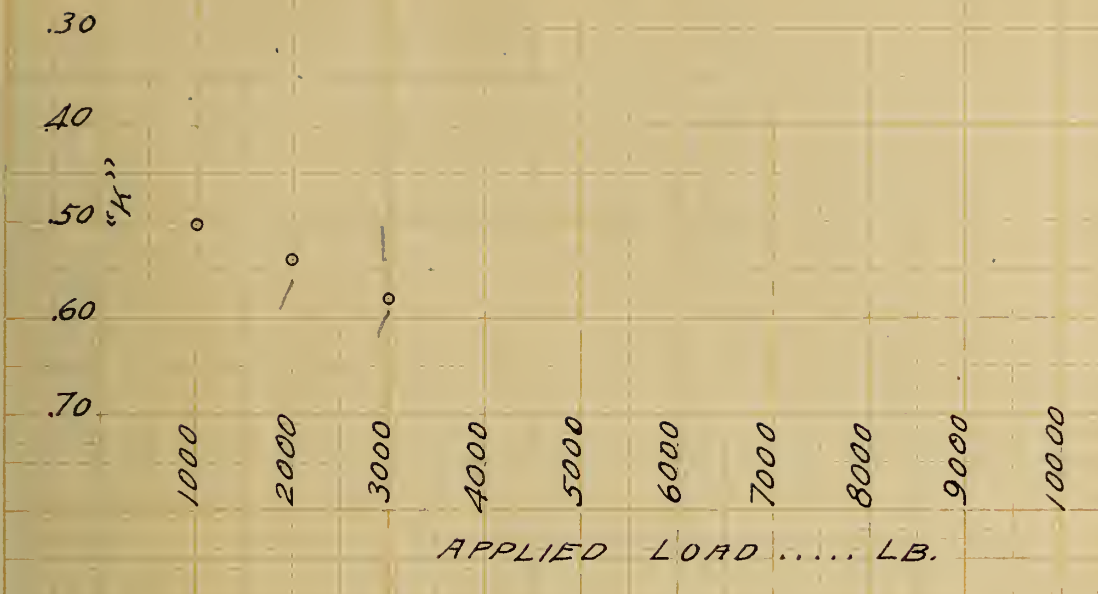

"K"
.30
.40
.50
.60
.70
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD .... LB.
APPLIED LOAD .... LB.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Upper Fiber
Steel
Deflection
BEAM NO. 335.2
MIXTURE 1-2-4
AGE ..... 69 DAYS
MAX. LOAD 11200 LB.
FAILURE TENSION
REINFORCEMENT .98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION..... IN.



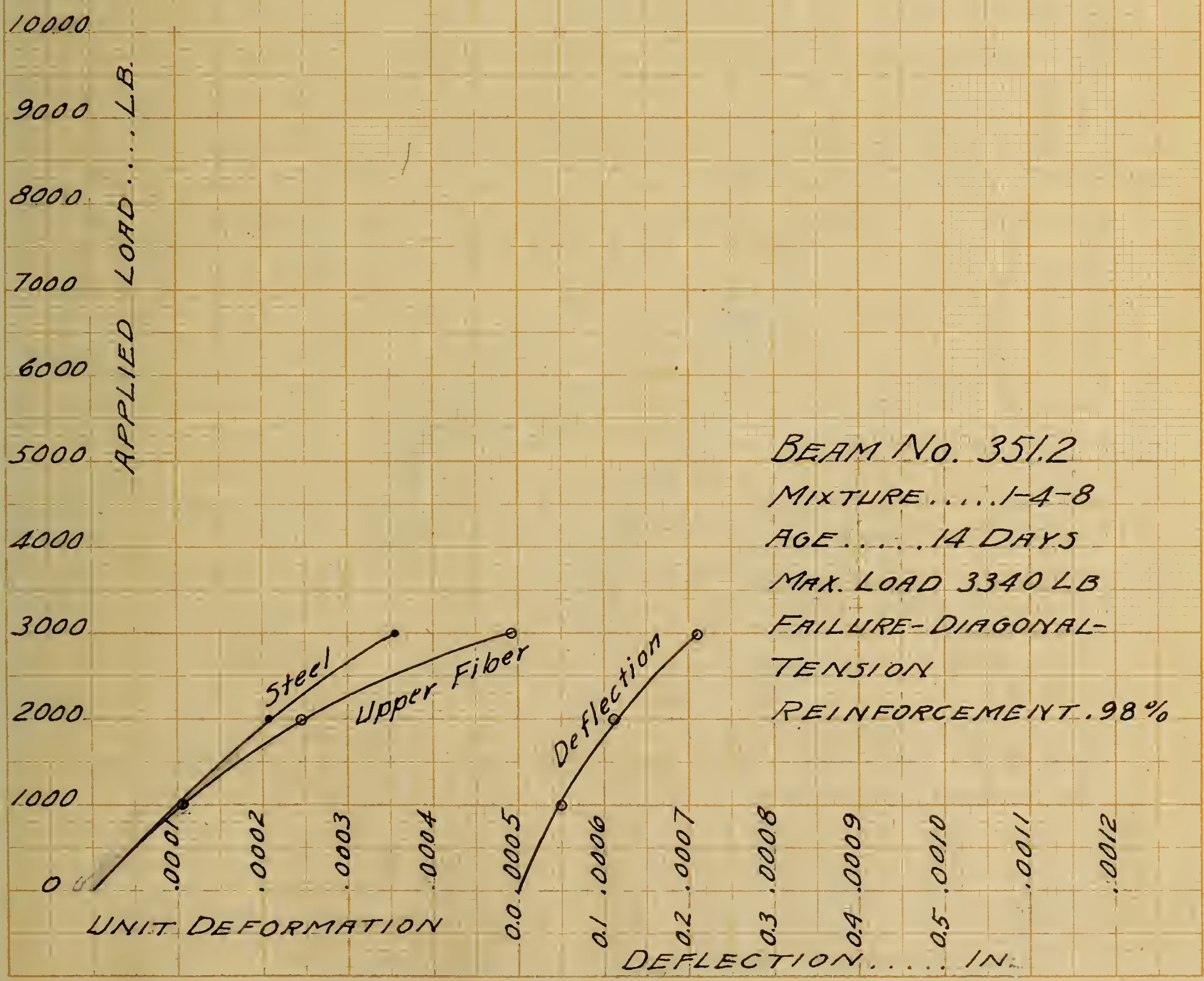
.30
.40
.50
.60
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD .... LB.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD .... LB.
Upper Fiber
Steel.
Deflection
BEAM No. 322.5
MIXTURE: . . .1-2-4
AGE . . . . . 383 DAYS
MAX. LOAD 12300 LB.
FAILURE TENSION
REINFORCEMENT .98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION. . . IN.



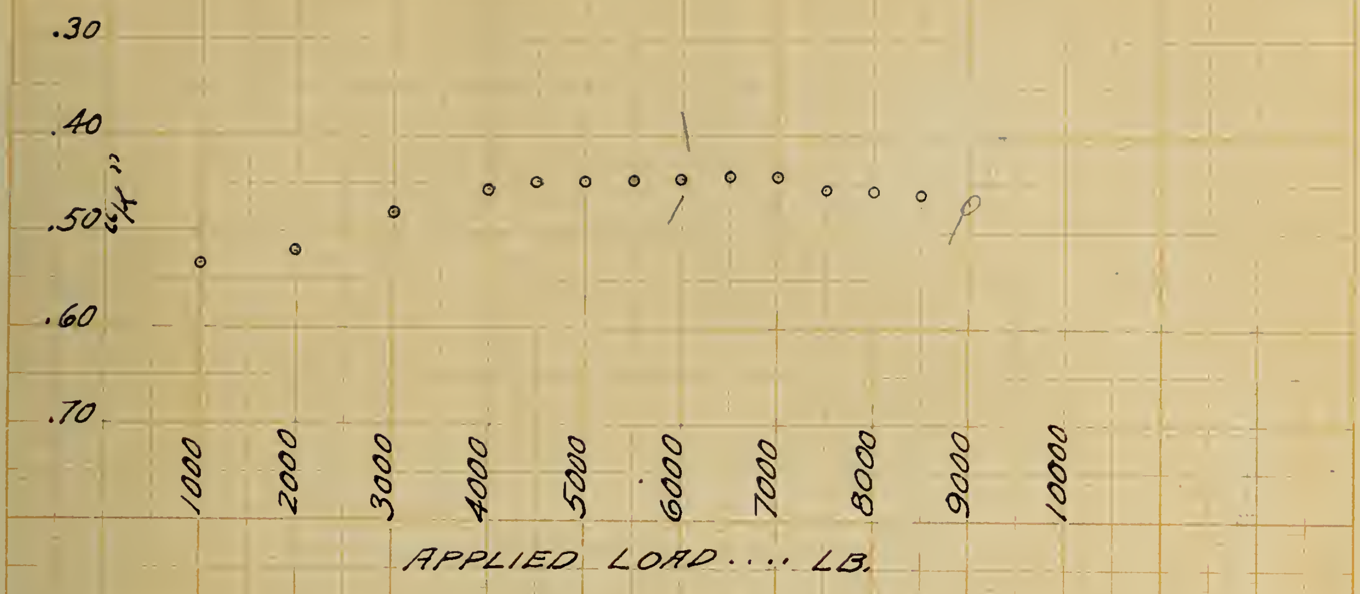
.30
.40
.50
.60
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
APPLIED LOAD.... LB.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD... LB.
Upper Fiber
Steel
Deflection
BEAM NO. 322.6
MIXTURE.. 1-2-4
AGE 383 DAYS
MAX. LOAD 11300 LB.
FAILURE TENSION
REINFORCEMENT .98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
.0013
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION... IN.



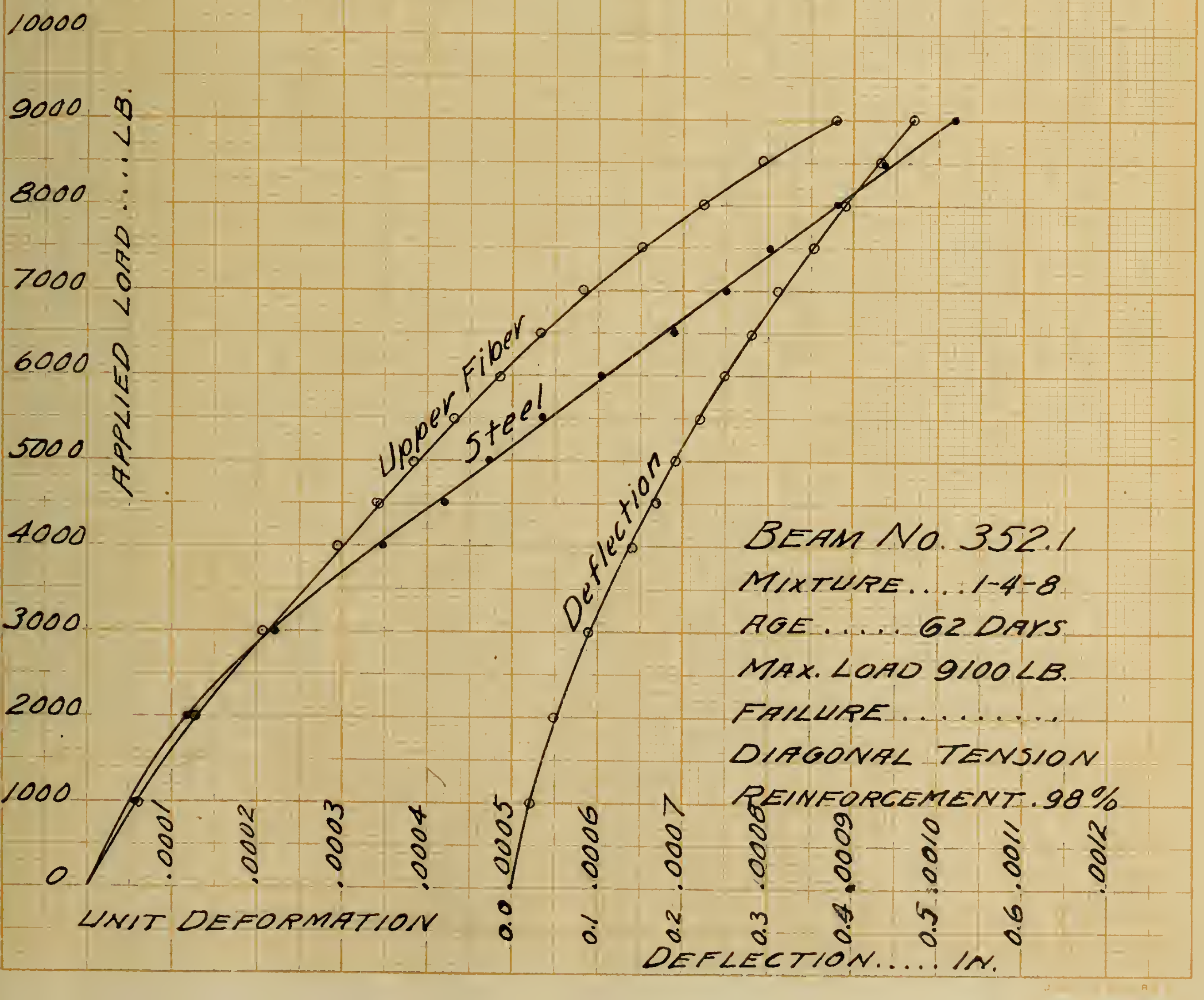
.30
.40
.50
.60
.70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
9000
100.00
APPLIED LOAD ..... LB.



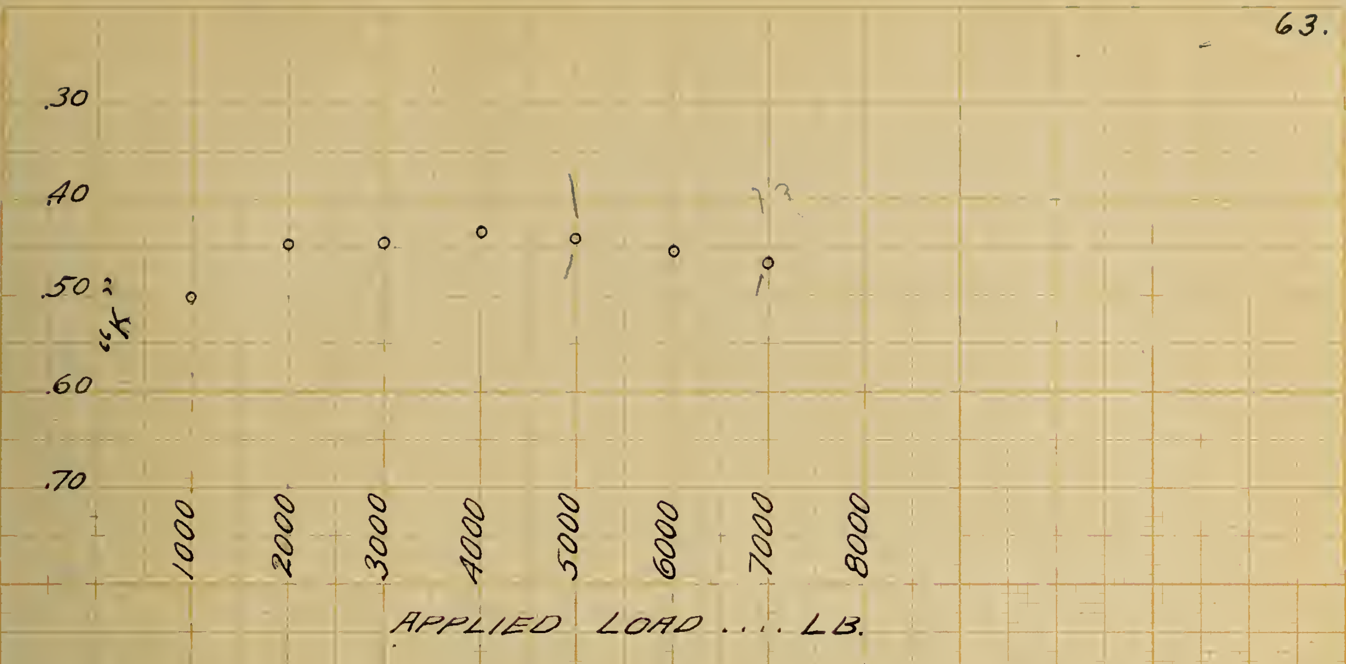
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD .... LB.
Steel
Upper Fiber
Deflection
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
DEFLECTION .... IN.
BEAM No. 351.2
MIXTURE 1-4-8
AGE......14 DAYS
MAX. LOAD 3340 LB
FAILURE-DIAGONAL-TENSION
REINFORCEMENT .98%

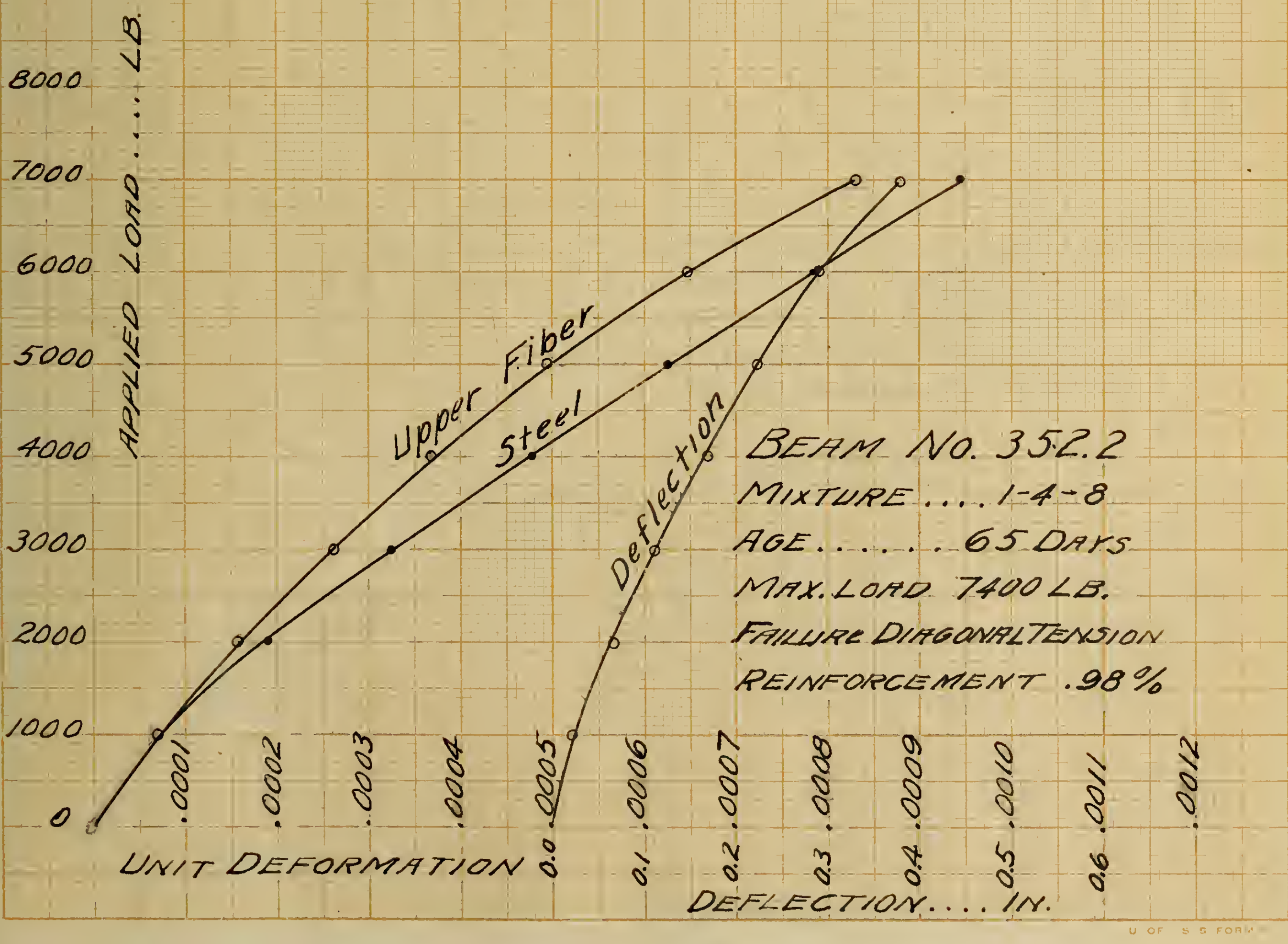


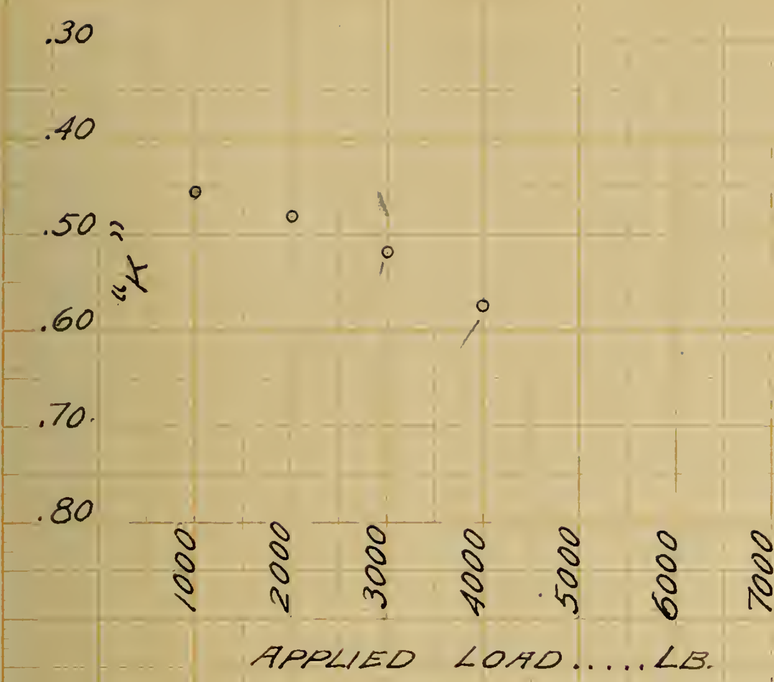
"K"
.30
.40
.50
.60
.70
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
APPLIED LOAD.... LB.

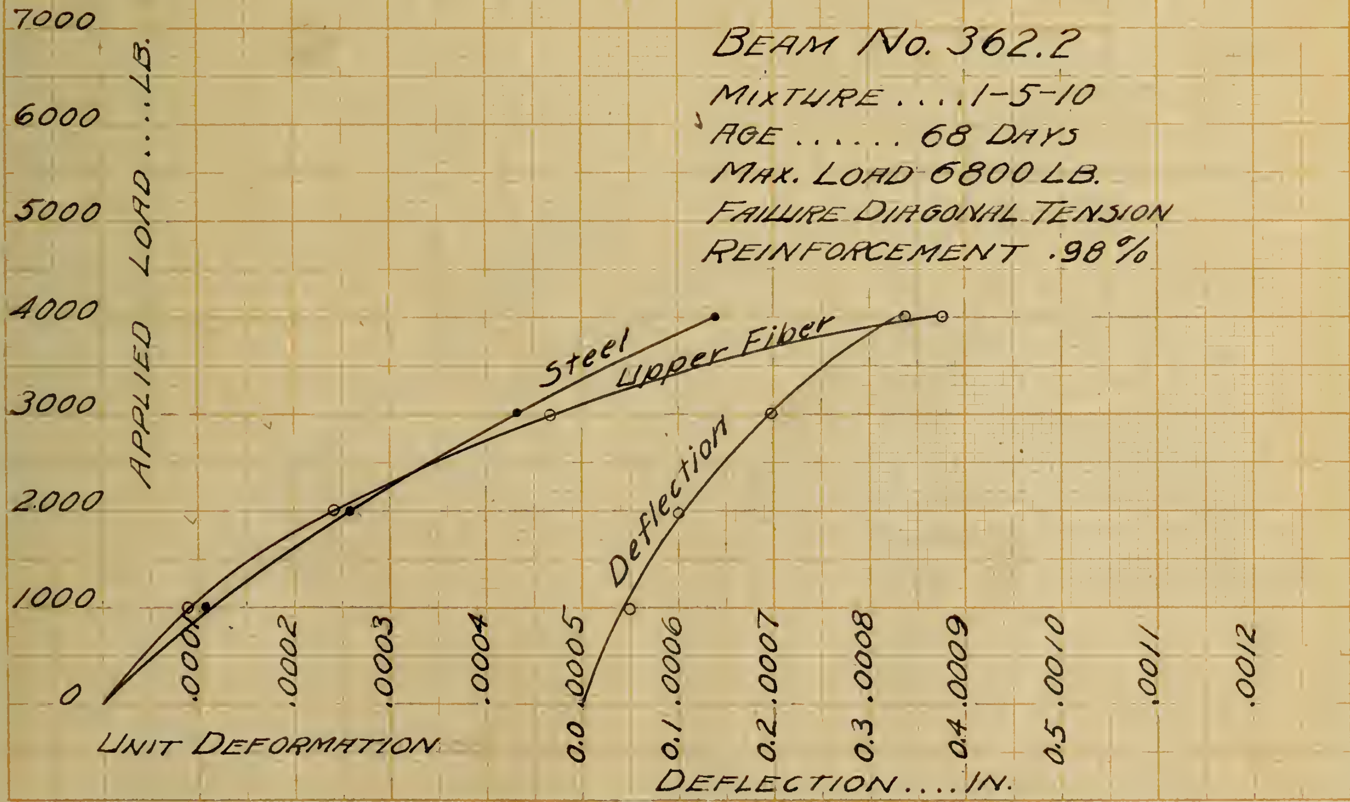


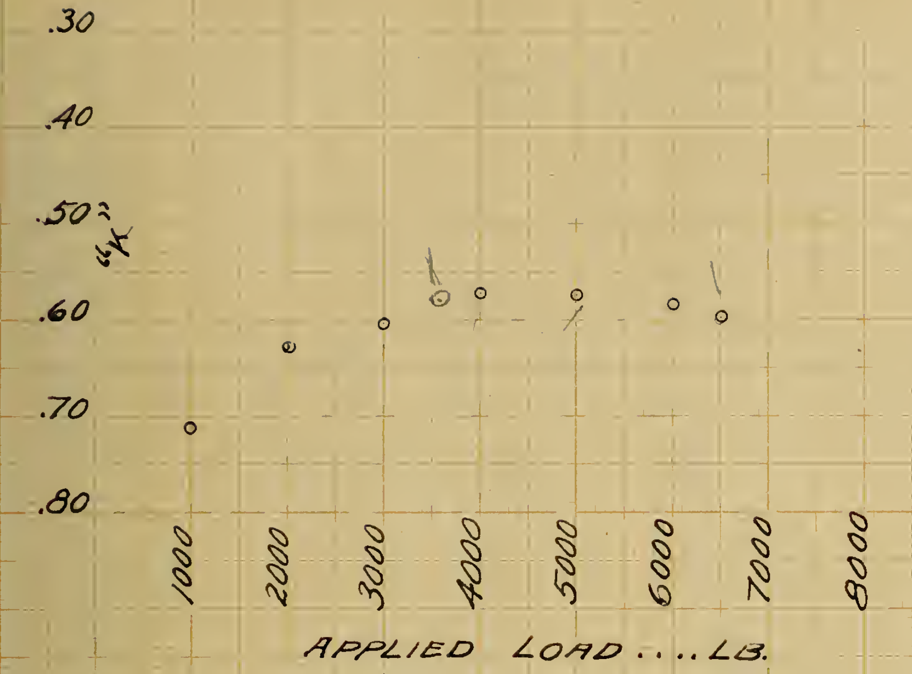
APPLIED LOAD.... LB.
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Upper Fiber
Steel
Deflection
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION.... IN.
BEAM NO. 352.1
MIXTURE....1-4-8
AGE..... 62 DAYS
MAX. LOAD 9100 LB.
FAILURE........
DIAGONAL TENSION
REINFORCEMENT .98%

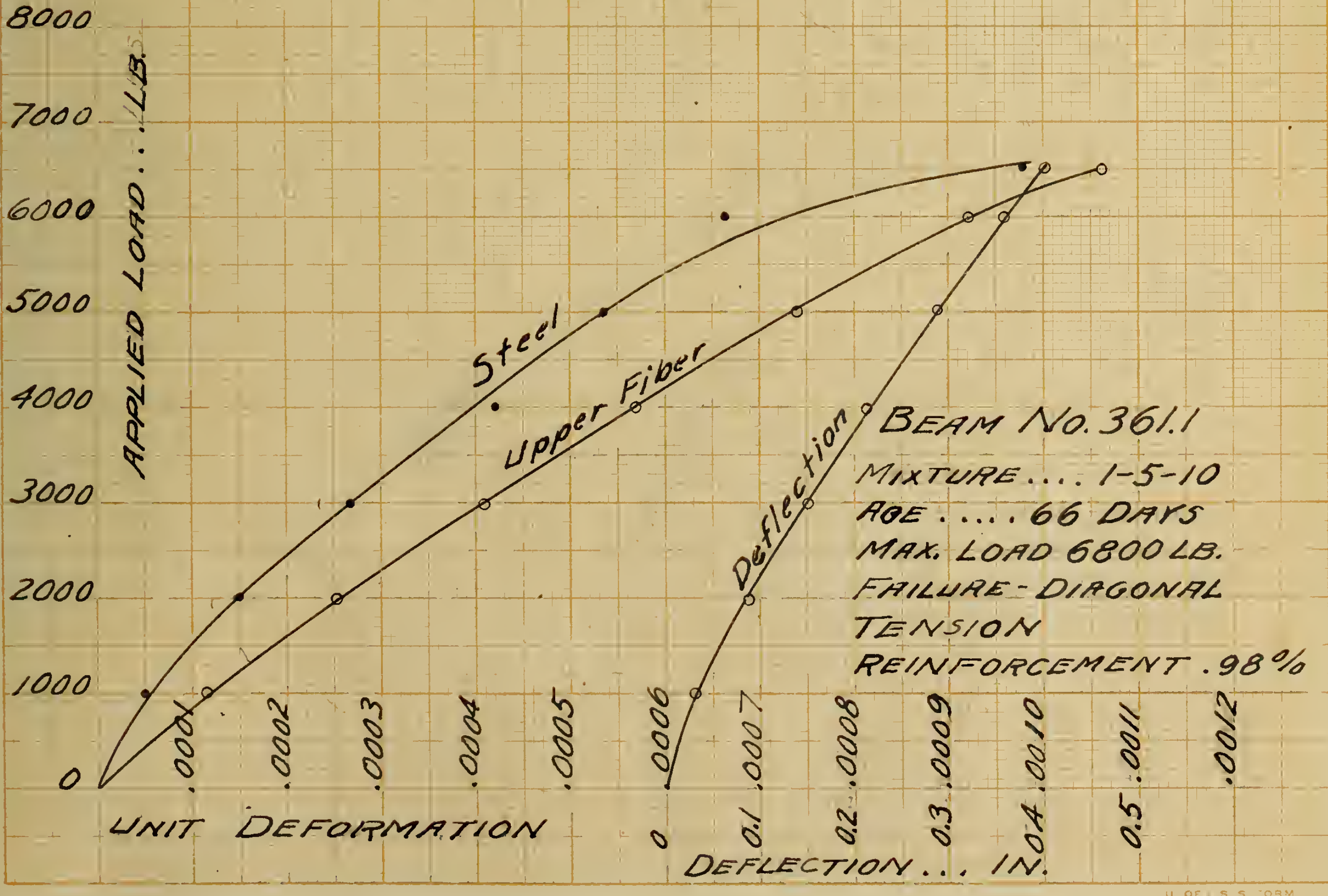

.30
.40
.50
.60
.70
"K"
1000
2000
3000
4000
5000
6000
7000
8000
APPLIED LOAD .... LB.

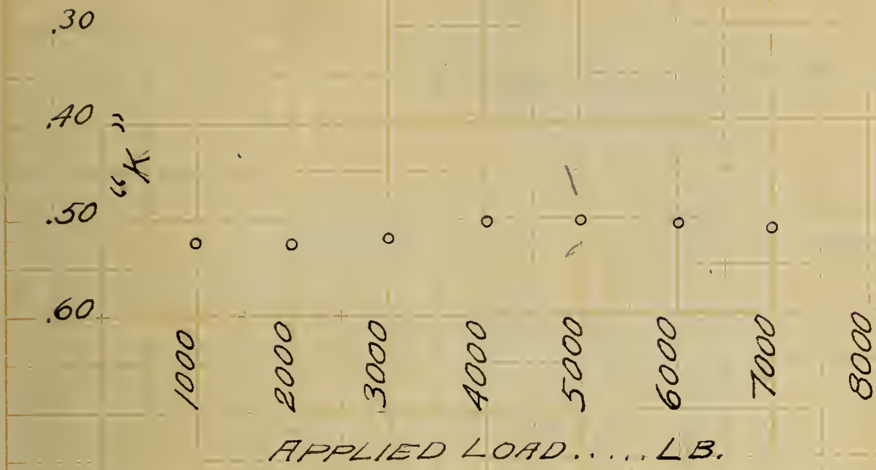

APPLIED LOAD .... LB.
8000
7000
6000
5000
4000
3000
2000
1000
0
Upper Fiber
Steel
Deflection
BEAM NO. 352.2
MIXTURE 1-4-8
AGE .... 65 DAYS
MAX. LOAD 7400 LB.
FAILURE DIAGONAL TENSION
REINFORCEMENT .98 %
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0.0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION .... IN.

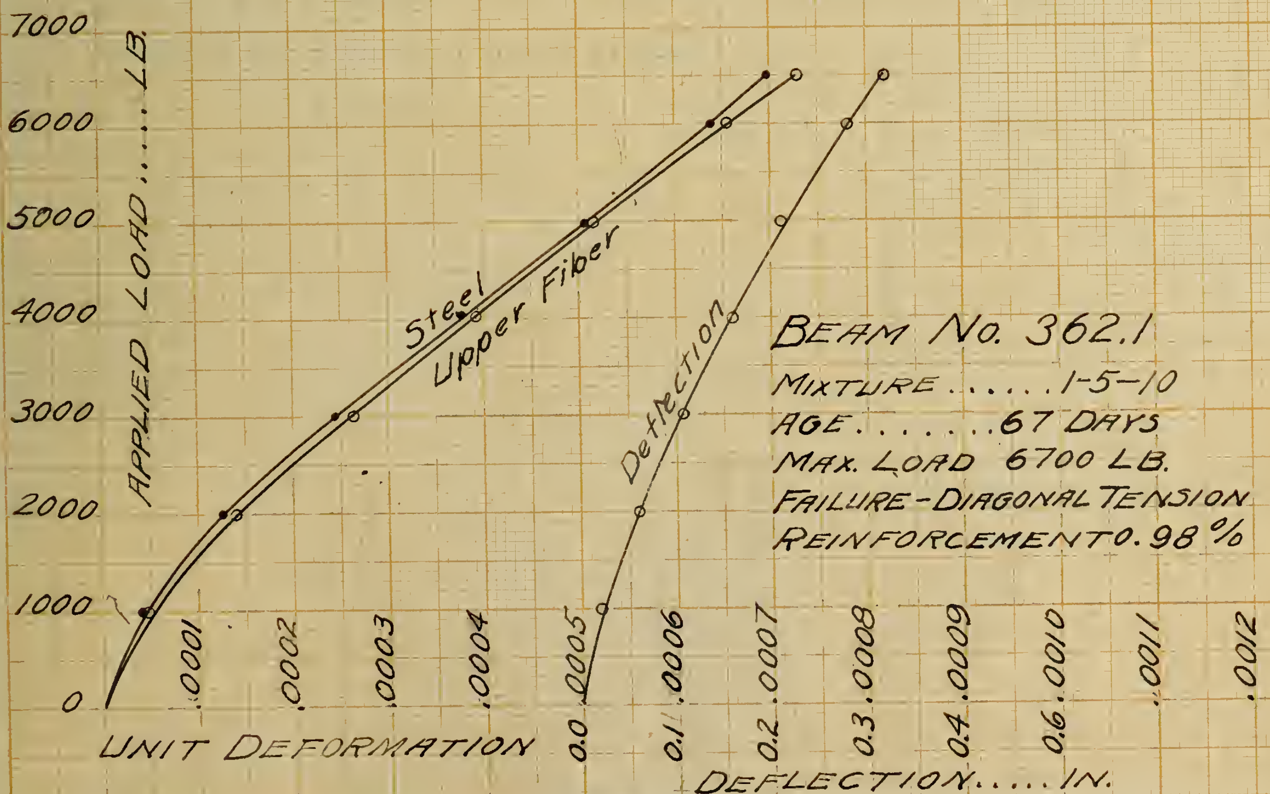

.30
.40
.50
.60
.70.
.80
"K"
1000
2000
3000
4000
5000
6000
7000
APPLIED LOAD.....LB.


BEAM No. 362.2
MIXTURE 1-5-10
AGE ...... 68 DAYS
MAX. LOAD 6800 LB.
FAILURE DIAGONAL TENSION
REINFORCEMENT .98%
7000
6000
5000
4000
3000
2000
1000
0
APPLIED LOAD....LB.
Steel
Upper Fiber
Deflection
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
0.0
0.1
0.2
0.3
0.4
0.5
UNIT DEFORMATION
DEFLECTION....IN.


"k"
.30
.40
.50
.60
.70
.80
1000
2000
3000
4000
5000
6000
7000
8000
APPLIED LOAD....LB.


APPLIED LOAD....LB.
8000
7000
6000
5000
4000
3000
2000
1000
0
Steel
Upper Fiber
Deflection
BEAM No. 361.1
MIXTURE.... 1-5-10
AGE.... 66 DAYS
MAX. LOAD 6800 LB.
FAILURE - DIAGONAL TENSION
REINFORCEMENT .98%
.0001
.0002
.0003
.0004
.0005
.0006
.0007
.0008
.0009
.0010
.0011
.0012
UNIT DEFORMATION
0
0.1
0.2
0.3
0.4
0.5
DEFLECTION... IN.





BEAM No. 362.1
MIXTURE......1-5-10
AGE.......67 DAYS
MAX. LOAD 6700 LB.
FAILURE-DIAGONAL TENSION
REINFORCEMENT 0.98 %

EXPLANATION OF TABLES.

TABLE IX.

This table contains the mixture, age, maximum load, stresses, and manner of failure of each beam. Under the heading, "Load Considered", are the loads for which the stresses in the steel andconcrete are considered. The stresses in the steel and concrete are computed as explained in Part III.

TABLE X.

This table contains the position of the neutral axis and the modulus of elasticity of each beam when gq= 1/4 and when gq = 1/2. "k" used in this table, as elsewhere in this thesis, represents the ratio of the distance between the compression face and the neutral axis, to the distance between the compression face and the center of the reinforcing steel. "g" is ratio of deformation existing in the most remote fiber to the ultimate or crushing deformation.

Table No. IX

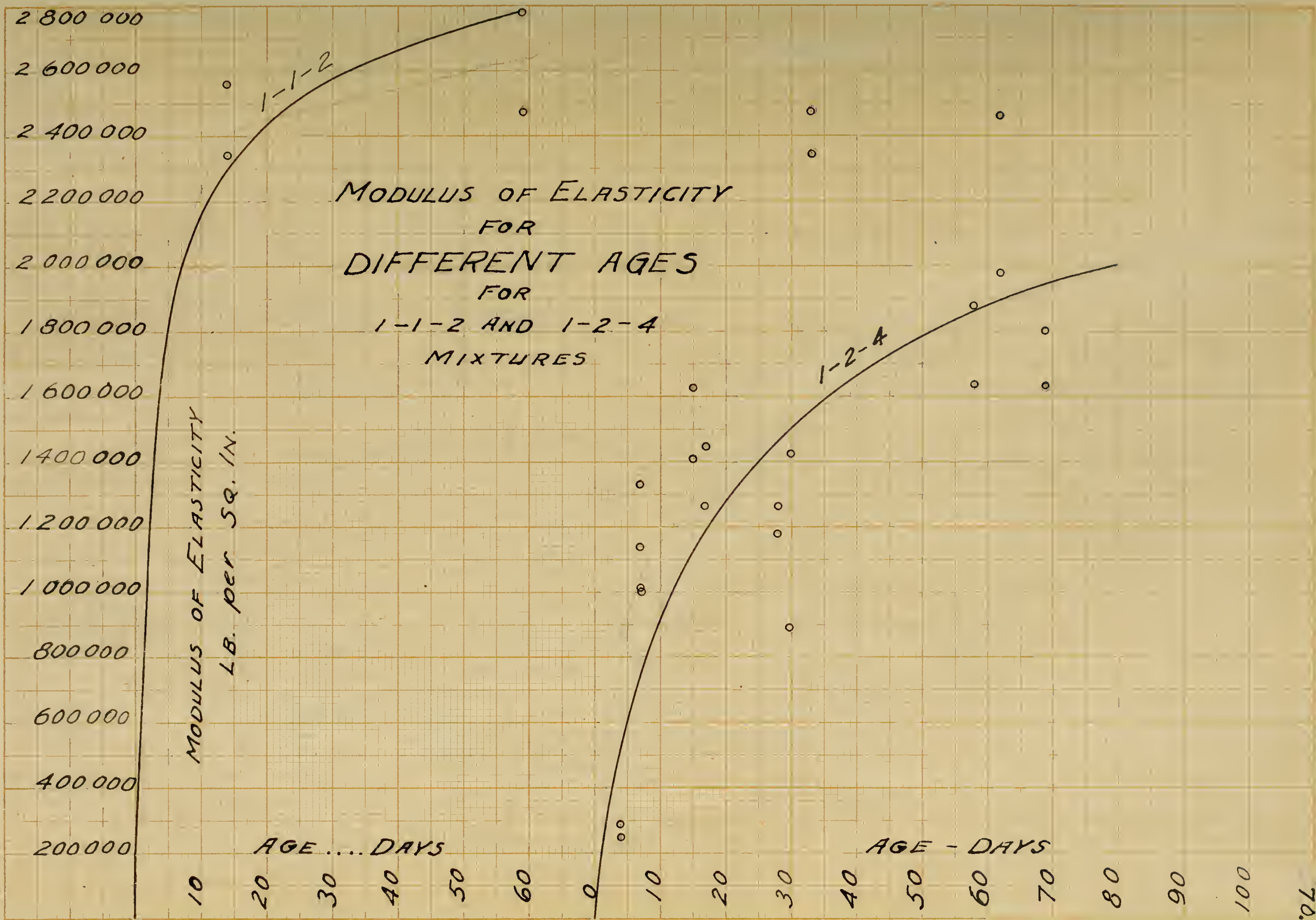
Stresses In Concrete And Steel

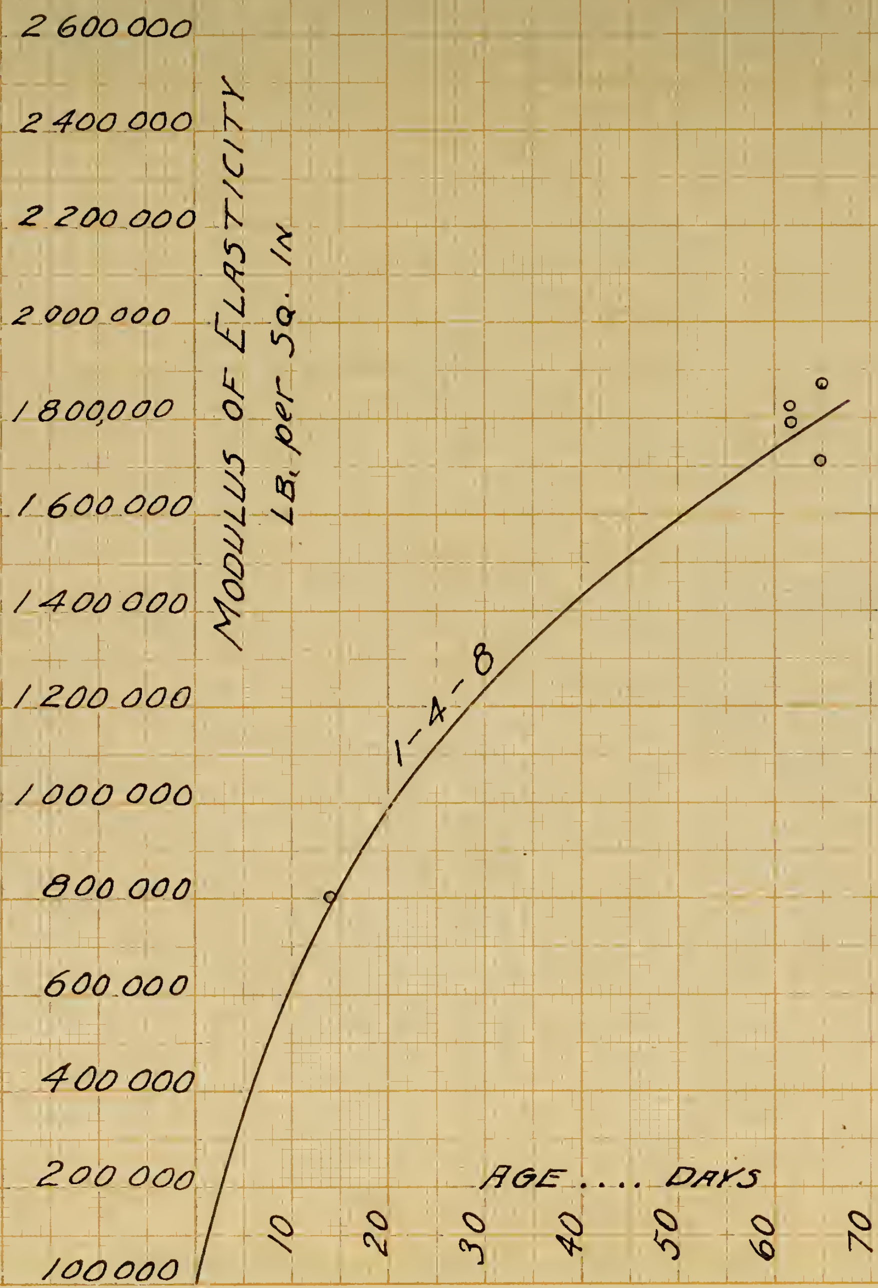
Beam No.	Mixture By Volume	Age Days	Maximum Applied Load Lb.	Load Considered Lb	Neutral Axis "k"	Calculated Stresses In Steel. Lb. Per Sq. In.		Calculated Stress In Concrete Lb. Per Sq. In.	Method Of Failure
						From Resisting Moment	From Deformation		
341.2	1-1-2	14	11320	11000	.409	39200	38700	1680	Tension
342.1	1-1-2	59	12200	12000	.378	42300	34500	1790	Tension
331.3	1-2-4	4	2900	2800	.830	12000	11300	210	Diagonal Tension
331.1	1-2-4	7	7750	7000	.620	27300	33200	780	"
332.1	1-2-4	7	8600	8500	.634	33400	31200	750	"
333.2	1-2-4	15	9040	8000	.496	33300	36900	1170	Tension
333.1	1-2-4	17	7500	7000	.520	26200	38000	1030	Diagonal Tension
334.3	1-2-4	28	9800	9000	.528	33800	36300	1080	Tension
334.2	1-2-4	30	11300	11000	.493	40600	31900	1290	"
334.1	1-2-4	33	11800	11000	.410	39300	37800	1660	"
331.2	1-2-4	58	12000	11000	.450	39800	35700	1560	"
335.1	1-2-4	62	11800	11000	.411	39200	34500	1690	"
335.2	1-2-4	69	11200	11000	.461	40000	35100	1540	"
322.5	1-2-4	383	12300	12000	.390	42500	36100	1770	"
322.6	1-2-4	383	11300	11000	.374	38700	40600	1870	"
351.2	1-4-8	14	3340	3000	.580	11400	10700	370	Diagonal Tension
352.1	1-4-8	62	9100	9000	.467	32800	30600	1240	"
352.2	1-4-8	65	7400	7000	.468	25600	28300	1040	"
362.2	1-5-10	68	4300	4000	.578	15300	19300	530	"
361.1	1-5-10	66	6800	6500	.598	26300	29400	820	"
362.1	1-5-10	67	6700	6500	.512	24200	20400	780	"

TABLE No. X

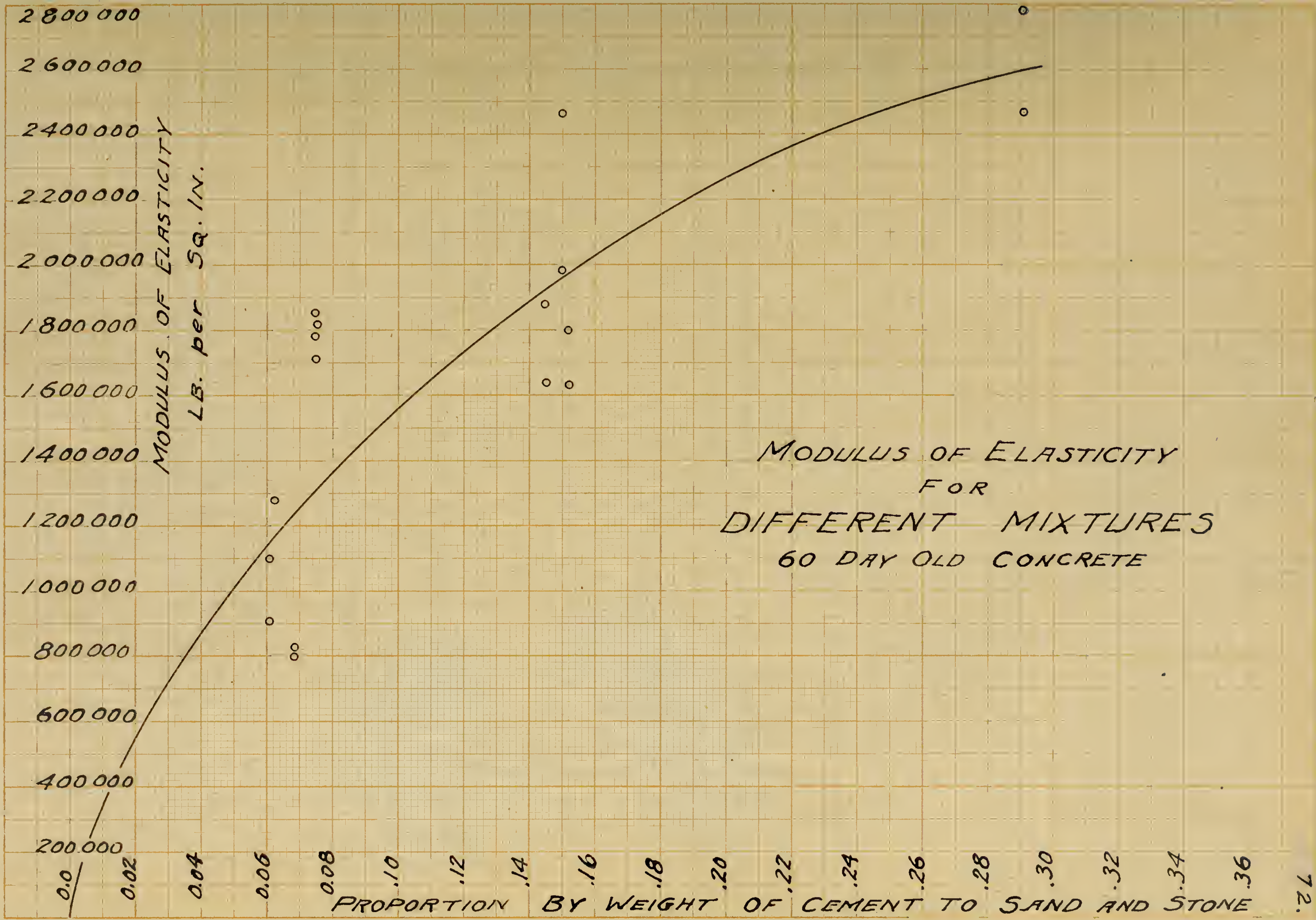
MODULUS OF ELASTICITY, E, FOR VARIOUS MIXTURES AND AGES.

Beam No.	Mixture By Volume	Age Days	$q = \frac{1}{4}$ "k"	$q = \frac{1}{4}$ E	$q = \frac{1}{2}$ "k"	$q = \frac{1}{2}$ E	Mean E
341.2	1-1-2	14	.404	2 342 000	.405	2 560000	2450000
342.1	1-1-2	59	.396	2 471 000	.393	2 780000	2 600000
331.3	1-2-4	4	.745	294000	.785	246000	270000
331.1	1-2-4	7	.540	1 013000	.510	1330000	
332.1	1-2-4	7	.513	1 142000	.560	998000	1120000
333.2	1-2-4	15	.462	1625000	.500	1413000	
333.1	1-2-4	17	.480	1446000	.520	1255000	1428000
334.3	1-2-4	28	.515	1175000	.520	1255000	
334.2	1-2-4	30	.556	890000	.497	1434000	
334.1	1-2-4	33	.404	2342000	.410	2475000	1500000
331.2	1-2-4	58	.459	1640000	.450	1880000	
335.1	1-2-4	62	.430	1975000	.410	2458000	
335.2	1-2-4	69	.461	1630000	.460	1800000	1900000
322.5	1-2-4	383	.402	2375000	.410	2475000	
322.6	1-2-4	383	.373	2895000	.375	3130000	2700000
351.2	1-4-8	14	.580	801000			801000
352.1	1-4-8	62	.443	1816000	.462	1782000	
352.2	1-4-8	65	.440	1852000	.468	1712000	1740000
362.2	1-5-10	68	.525	1104000	.575	908000	
361.1	1-5-10	66	.580	803000	.590	833000	
362.1	1-5-10	77	.502	1275000			1000000


MODULUS OF ELASTICITY
FOR
DIFFERENT AGES
FOR
1-1-2 AND 1-2-4
MIXTURES
1-1-2
1-2-4
MODULUS OF ELASTICITY
LB. per SQ. IN.
2 800 000
2 600 000
2 400 000
2 200 000
2 000 000
1 800 000
1 600 000
1 400 000
1 200 000
1 000 000
800 000
600 000
400 000
200 000
AGE .... DAYS
10
20
30
40
50
60
AGE - DAYS
0
10
20
30
40
50
60
70
80
90
100



MODULUS OF ELASTICITY
FOR
DIFFERENT AGES
FOR
1-4-8 MIXTURES


MODULUS OF ELASTICITY
FOR
DIFFERENT MIXTURES
60 DAY OLD CONCRETE
MODULUS OF ELASTICITY
LB. per SQ. IN.
2 800 000
2 600 000
2400 000
2200 000
2 000 000
1 800 000
1 600 000
1400 000
1 200 000
1 000 000
800 000
600 000
400 000
200 000
0.0
0.02
0.04
0.06
0.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
PROPORTION BY WEIGHT OF CEMENT TO SAND AND STONE

PART IV.

DISCUSSION AND EXPERIMENTAL DATA.

DISCUSSION:

The following is a short description of the action of a few representative beams during the testing.

In beam No. 342.1, a 59-day, 1-1-2 mixture, the deformations of the fibers of the beam were nearly proportional to the load up to a load of 6000 lb. The load-deformation curves show that at a load of 6000 lb. the beam yielded considerably, but that soon after passing this load the deformation once more became proportional to the load applied. This last rate of deformation, which was faster than before, continued until the beam failed.

The first hair crack appeared a little to the left of the center at a load of 7000 lb. Other cracks appeared at loads of 8000, 9000 and 10000 lb. The failure occurred by tension in the steel near the center of the beam at a load of 11,300 lb. One of the two failure cracks was the first hair crack that appeared, while the other failure crack was the last one that was noticed.

Beam No. 335.2, which is representative of the three 60-day 1-2-4 mixtures, acted much as beam No. 342.1, except that the change in the rate of deformation was not so abrupt and this change came at a smaller load, about 4000 lb. Also the rate of deformation increased rapidly while the last 1000 lb.

was being applied. Many hair cracks appeared in this beam, the first ones appeared at a load of 6000 lb. About a dozen cracks were noticed before the failure crack, which appeared at a load of 11000 lb. The beam failed by tension, 3 in. inside of one of the load points, at 11200 lb.

In beam No. 352.1, which was a 62-day 1-4-8 mixture, there was also a slight break in the load-deformation curve at a load of 2500 lb. In the curves of all three beams mentioned the change in the rate of deformation both of the concrete and the steel occurred at a unit deformation of about 0.0002. The curve of beam No. 352.1 had more nearly the characteristics of a parabola than those of two straight lines as occurred in the first-mentioned curves.

The first hair crack appeared at a load of 7500 lb., the second and last, which was the failure crack, occurred at a load of 8500 lb. The beam failed slowly by diagonal tension at 9100 lb.

In beam No. 361.1, which was a 66-day 1-5-10 mixture, the curve bends more than the ones for the 1-4-8 mixtures. No resemblance of a yield was noticeable in this load-deformation curve. One hair crack appeared at 5000 lb. and another at 6000 lb. The beam failed suddenly by diagonal tension at a load of 6800 lb.

Beam No. 331.3, a 4-day 1-2-4 mixture, failed slowly by diagonal tension at a load of 2900 lb. Its load-deformation curve bends very rapidly, and, as would be expected, has no

point of sudden yielding as was noticed in the older beams of the same mixture.

In beam No. 322.6, a 383-day 1-2-4 mixture, the load-deformation curve bends considerably up to a load of 2000 or 3000 lb., at which point the deformation is about 0.00015. After this the curve is nearly a straight line until the beam failed. The first hair crack appeared at a load of 5000 lb. The failure crack, which was near the center of the beam, was noticed at a load of 8000 lb. The beam failed by tension at 11300 lb.

The first appearance of hair cracks, which is the first visible sign of failure of the concrete in tension, seems to be influenced very little by the age or the quality of the concrete. This is probably so, because, even though the leaner and the younger mixtures do break apart sooner, the cracks are not visible to the naked eye until the steel elongates an amount that is sufficient to allow the crack to widen enough to become noticeable. This elongation of the steel in the different beams does not vary very much, hence the cracks first began to appear in all the beams at about the same load-between 5000 lb. and 7000 lb.

In some of the leaner and younger beams no hair cracks appeared as the applied load did not reach 6000 lb. or 7000 lb before failure. All of the 1-4-8 and 1-5-10 mixtures, as well as the 4-, 7-, and one of the 14-day beams of the 1-2-4 mixtures failed by diagonal tension.

The results are such as one would expect-that is, the richer and older mixtures failed by tension in the steel, while the leaner and younger mixtures failed by diagonal tension in the concrete. From these tests it appears that a 14-day 1-2-4 mixture is liable to fail either by tension or by diagonal tension. A leaner or a younger beam than this would be more liable to fail by diagonal tension, while a richer or an older one would be more liable to fail by tension.

Table No. X. gives the modulus of elasticity as calculated for each beam, together with the age and mixture. The results are more easily and better understood in graphical form as shown on pages 70, 71, and 72. Curves on pages 70, and 71 show that in all mixtures the modulus of elasticity increases with the age of the beam, and that this increase is much slower the older the beam becomes. They also show that the modulus of elasticity increases faster with the richer mixtures during the earlier ages. The curve on page 72 shows that for the age of 60-days the modulus of elasticity increases as the mixture grows richer, but that the rate of increase gradually grows less as the richer mixtures are reached.

The average values of the modulus of elasticity obtained for different mixtures and ages are as follows:

For the 1-1-2- mixture the average value was about 2,600 ,000 lb. per sq. in., the 14-day one being 2,400,000 lb. per sq. in. and the 59-day one being 2,700,000 lb. per sq. in. For the 1-2-4 mixtures, the average value for 30-day beams was about 1,500,000 lb. per sq. in., for the 60-day ones about 1,900,

000 lb. per sq. in., and for the year beams about 2,700,000 lb. per sq. in. The largest variation occurred with the three 30-day beams, the value for one beam being 1,000,000 lb. per sq. in. and for another being 2,400,000 lb. per sq. in. The largest variation from the 60-day average value was 300,000 lb. per sq. in. The year beams values varied 200,000 lb. per sq. in. from the average. For the 1-4-8 mixtures the average value for both 60-day beams was 1,740,000 lb. per sq. in. The value for the one 14-day beam was 800,000 lb. per sq. in. The average value for the three 60-day 1-5-10 mixtures was 1,000,000 lb. per sq. in., the largest variation being 200,000 lb. per sq. in.

As a whole, the values for the modulus of elasticity, for beams of the same age and mixture, agreed very closely.

The above results correspond favorably with the results given in Bulletin No. 4 of the University of Illinois Engineering Experiment Station, which states that a constant modulus of elasticity of about 2,000,000 lb. per sq. in. is probably about the proper value for ordinary mixtures of concrete. The results agree even more closely with those computed in the theses of Messrs. Bagby and Casey, and of Messrs. Galhuly, Miller and Lewis of the class of 1907 of the University of Illinois.

The curve obtained, showing the relation between the modulus of elasticity and the percent of cement in the mixtures, has more of a parabolic form than the corresponding curve of the first named thesis.

For equal loads the younger and the leaner beams deflected more than the older and the richer ones, but the maximum deflection was greater in the older and richer beams.

PART V.

CONCLUSION.

The conclusions drawn from these tests are:

First:- In all mixtures the modulus of elasticity increases with the age of the beam, and the rate of increase becomes less as the beam grows older.

Second:- The richer the mixture the greater proportionally is the modulus of elasticity for the younger ages.

Third:- The modulus of elasticity increases with the richness of the concrete, but this increase is not directly proportional to the richness, but rather bears a parabolic relation to it.

Fourth:- The leaner the mixture the more likely are the diagonal tension stresses to affect the failure of a beam.

Fifth:- Average values of modulus of elasticity for various ages and mixtures are as follows:

30-day,	1-2-4 mixtures	1500000 lb. per sq. in.
60-day,	1-2-4 mixtures	1900000 lb. per sq. in.
1-year,	1-2-4 mixtures	2700000 lb. per sq. in.
60-day,	1-4-8 mixtures	1740000 lb. per sq. in.
60-day,	1-5-10 mixtures	1000000 lb. per sq. in.